UNIVERSITY OF CAPE COAST

ASSESSMENT OF BENTHIC MACROINVERTEBRATES BIODIVERSITY WITHIN THE KETA LAGOON COMPLEX RAMSAR SITE

BY

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FEBRUARY, 2023

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature Date……………………

Name:…………………………………………………………………………….

Supervisor's Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature……………………… Date…………………

Name:……………………………………………………………………………..

Co-Supervisor's Signature…………………………… Date…………………

Name:…………………………………………………………………………….

ABSTRACT

This study was aimed at conducting ecological assessment of the benthic macroinvertebrates biodiversity within the Keta Lagoon Complex Ramsar Site (KLCRS). This was done by assessing macroinvertebrates biodiversity, water and sediment quality and evaluating the interactions among these parameters. Environmental and biological samples were collected from five communities (Anloga, Tegbi, Havedzi, Fiaxor and Atiavi) within the KLCRS from January to July, 2022. Water physicochemical parameters were measured *in situ* using appropriate meters, whereas pesticides, nutrients, sediment particle sizes and organic matter determinations, as well as benthic macroinvertebrates identification were done in the laboratory. Canonical Correlation Analysis was used to determine the influence of the environmental parameters and the abundance of the benthic macroinvertebrates. Twenty four (24) species were recorded in the five communities. Four taxonomic groups namely; Polychaeta, Mollusca, Crustacea and Insecta of benthic macroinvertebrates were identified. The least number of species was encountered in Atiavi (13 species), followed by Anloga (15 species), Fiaxor (16 species) Havedzi (17 species) and Tegbi (19 species). Havedzi had a more diverse assemblages of organisms followed by Anloga, Fiaxor, Atiavi and Fiaxor. For water quality measurements, conductivity, total dissolved solids and dissolved oxygen were within the levels whereas nitrate and phosphate were above the levels recommended for aquatic environments. For sediment quality measurements, nitrate and phosphate were above the levels recommended for aquatic environments. Environmental parameters that significantly affected the abundance of benthic macroinvertebrates were nitrate, organic matter and pH.

KEY WORDS

Benthic macroinvertebrates

Coastal Lagoons

Diversity

Keta Lagoon

Water quality parameters

Sediment parameters

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DEDICATION

To my family, for their continuous support and love

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LIST OF ACRONYMS

ANOVA: Analysis of variance

BOD: Biological Oxygen Demand

DO: Dissolved Oxygen

GSA: Ghana Standards Authority

MPS: Mean particle sizes

OM: Organic matter content

TDS: Total dissolved solids

USEPA: United State Environmental Protection Agency

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Coastal lagoons have distinct features which make them different from other ecosystem types (Keddy, 2010). They are aquatic ecosystems in the transition between sea and land, that have a lot in common with estuaries in terms of features and processes. They can be found all over the world and often parallel to the coast. They are separated from the ocean by a barrier, connected to it by one or more restricted inlets that are open at least intermittently and with water depths of only a few meters (usually bellow 60 metres) (Kjerfve, 1994). Lagoons are valuable ecosystems in Ghana (Lamptey et al., 2013) and they are also part of the first ecosystems to get global attention through the "Convention on Wetlands of International Importance," which opened for signature in Ramsar, Iran, in 1971 (Kuijken, 2006).

Coastal lagoons provide key ecological services which includes protection of biodiversity such as fish, birds, flora and polychaete species (Scott, Frail-Gauthier & Mudie, 2014). This makes them key sensitive habitats and also environments suitable for human activities (Addo et al., 2014). Although there are several and complex reasons for coastal environmental decline (such as climate change), population growth plays a significant role in the main threats to coastal ecosystems (Creel, 2003). Coastal lagoons serve as habitats that are highly relevant in terms of providing ecosystem services such as shelter, breeding areas and nursery grounds for a lot of organisms (Broszeit et al., 2022). They sustain complex interactions of marine and terrestrial habitats, which supports high biodiversity and complex life cycles and food webs. People living around lagoons depend on a variety of resources, which includes mangroves for wood fuel, and fish for food. However, over the past years, Ghana's coastal lagoons are under grave threat from both human activity and natural occurrences at a rate which is alarming (Karikari, Asante & Biney, 2009), endangering the health and biodiversity of these ecosystems.

Biodiversity, in broader terms, refers to the variety of living species found in all environment, including terrestrial and aquatic ecosystems (Snelgrove, 1999). This includes diversity within and between species, as well as within and across habitats (Snelgrove, 1999). Biodiversity is usually used as a proxy for ecosystem health, high biodiversity indicates good health of the ecosystem, while less biodiversity indicates poor health of the ecosystem. Biodiversity of coastal lagoons make them serve as one of the major sources of livelihood for people living around them. They sustain artisanal fisheries, which provide a considerable amount of the economic and food resources for the people (Dankwa, Shenker, Lin, Ofori-Danson, & Ntiamoa-Baidu, 2004). For many years, a number of activities, including fishing with various techniques, cutting reeds for thatch and weaving, gathering salt, and irrigating vegetable fields in and around lagoons have caused an increase in exploitation of its resources (Finlayson, Gordon, Ntiamoa-Baidu, Tumbulto, & Storrs, 2000). This has resulted in degradation and decline of resources and important fauna, including benthic macroinvertebrates within lagoons (Finlayson, Gordon, Ntiamoa-Baidu, Tumbulto, & Storrs, 2000).

Benthic macroinvertebrates are bottom dwelling aquatic organisms that do not have a backbone and can be seen without the aid of a microscope

(Yusuf, Abdulkarim & Indabawa, 2019). They are found attached to rocks or within the tiny spaces found within rocks, sticks or burrowed in the sediment of aquatic ecosystems (Nkwoji, Ugbana & Ina-Salwany, 2010). Their distribution generally gives an indication of the health of an aquatic ecosystem. Since they spend most of their life cycle living within or on the sediment which is usually a major repository and source of pollutants, they become good indicators of the health of the water body (Sallenave, 2015). They are crucial to the food web and make up majority the of species present in both the water and sediment (Dzakpasu, Yankson & Blay, 2015). The aquatic food chain and all aquatic resources are affected when there are environmental effects on these organisms (Wuana & Okieimen, 2011). Some aquatic benthic macroinvertebrates are known to be less or more tolerant to pollution and their absence or presence can be used to determine whether the environment is of good or bad quality. Some also offer cleaning services in the ecosystem. They do this by scavenging dead or decaying plants, animals and bacterial and also filter the water through their feeding process (Shachi, Kumar & Prasad, 2020). High nutrient inputs however, alter vegetative ecosystems because they give some photosynthetic organisms a competitive edge in terms of food and space (Randall, Wotherspoon, Ross, Hermand, & Johnson, 2019). The extent to which harmful algal blooms affect benthic habitats can vary, but they can cause widespread mortality and increase disease prevalence in the benthic fauna (Anderson et al., 2021). In other instances, the bacterial breakdown of these phytoplankton blooms causes the coastal lagoons to become anoxic or "dead zones," where the majority of marine life cannot live due to low dissolved oxygen levels (Welch, 2021). Both nutrient and sediment loading from agricultural activities increases turbidity which reduces the availability of light thereby, reducing primary production, which in turn impacts negatively on the ecosystem (Lemley, Adams & Taljaard, 2017). Additionally, the sediment has the potential to cause harm to delicate habitats and also harm fish larval development (Wenger et al., 2014). However, sampling these macroinvertebrates is easy and has no negative consequences on other organisms (Sallenave, 2015). Several academics have used them globally for ecological evaluation as a result of some of these qualities.

There is little information on benthic macroinvertebrates biodiversity in the Keta Lagoon Complex Ramsar Site (KLCRS). Meanwhile, these organisms provide vital information on the quality of water and play significant functions in the ecosystem such as water purification and making up majority of the organisms in the lagoon as they serve as food for most of the organisms.

1.2 Statement of Problem

Tropical coastal lagoon systems are poorly understood (Alongi, 1990) and Ghana’s coastal lagoons, including the Keta Lagoon do not seem to have been the subject of specific faunal assessments (Attuquayefio, Raxworthy & Ryan, 2005). Although there have been many biodiversity assessments within the Keta Lagoon, most assessments have focused on changes in biodiversity of higher-level organisms like reptiles, fish, birds and mammals (Attuquayefio, Raxworthy & Ryan, 2005; Dankwa, Shenker, Lin, Ofori-Danson, & Ntiamoa-Baidu, 2004; Lamptey & Ofori-Danson, 2014). There is also little information and data on macrobenthic fauna in the Keta Lagoon (Attuquayefio, Raxworthy & Ryan, 2005). However, the information on these organisms such as benthic macroinvertebrates within the lagoon over the years has not been detailed enough (Lamptey, 2008) despite the important ecological roles these taxa perform in the aquatic ecosystem. Also, the activities of people living in coastal communities may negatively impact the benthic macroinvertebrates.

1.3 Research Objectives

The main aim of this study was to conduct ecological assessment of the benthic macroinvertebrates biodiversity within the Keta Lagoon Complex Ramsar Site (KLCRS).

The objectives of the study were to:

i. assess water quality of the KLCRS using physicochemical parameters.
ii. assess sediment quality of the KLCRS.
iii. assess the biodiversity of benthic macroinvertebrates in the KLCRS.
iv. determine the relationship between physicochemical parameters, sediment quality and the benthic macroinvertebrates biodiversity.

1.4 Significance of Study

This study provides information on ecology of benthic macroinvertebrates within the KLCRS in terms of abundance, distribution, biodiversity and interactions of these biotic parameters with selected abiotic components of this important ecosystem. The accrued information will form a basis for the assessment of lower-level organisms and also provide a scientific database that would lead to an increased understanding of the Keta Lagoon and Ghana’s coastal wetlands as a whole. The documentation of the biodiversity of benthic macroinvertebrates in the KLCRS will also form part of the focus of the long-term conservation programmes that forms part of Ghana’s commitment to the Convention of Biodiversity (Attuquayefio, Raxworthy & Ryan, 2005) for effective management strategies for the wetland.

1.5 Delimitations

Pesticides analysis was conducted at the Ghana Standards Authority (GSA) Pesticides Laboratory and to reduce the cost, sediment and water samples were composited at each station for analysis. For the same reason of cost, analysis was done only for two months (representing dry and wet seasons) instead of the entire study period. Nitrate and phosphate determinations were supposed to have occurred within 24 hours of sampling. However, in cases where schedules did not allow analysis to be done immediately, samples were refrigerated at 4 ^{o}C and analysed within 48 hours.

1.6 Limitations

Sampling during the study was done monthly, precisely in the fourth week of every month. However, due to time constraints, sampling for May was done in the first week. Periphyton samples were also collected only at the lower-stream in all the communities due to unavailability of rocks and sticks at the middle and upper-streams.

1.7 Organisation of the Thesis

Six chapters make up this thesis. Chapter One focuses on the concept of the study, giving the background information on coastal lagoons and benthic macroinvertebrates, statement of problem, objectives and significance of the study, delimitations and limitations. Chapter Two is made up of relevant literature reviews related to the study. Chapter Three outlines the methods and statistical tools and application used to collect and analyse the data. The study area was also described in this chapter. Chapter Four covers the results, presenting data on physicochemical parameters, sediment quality parameters, occurrence and composition of macroinvertebrates in the study areas. Chapter

Five discusses the results presented. It interpretates the findings and compares with other studies. Chapter Six gives a summary of the research findings, along with conclusions and suggestions for further studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In recent years, there has been an increased interest in coastal lagoons. This is due to the numerous benefits provided by these ecosystems and their ability to offer important services for human sustenance (Carabine, Cabot Venton, Tanner & Bahadur, 2015). Some of which include the movement of people and goods, fishing, and provision of natural resources such as mangroves. Agricultural practices, municipal or industrial waste disposal, and indiscriminate fishing has caused the degradation of these water bodies (Bukola, Zaid, Olalekan & Falilu, 2015). These factors put a lot of strain on coastal lagoons, thereby resulting in modification of both water quality and habitat, and loss of biodiversity (Prosser et al., 2019). This chapter emphasises on the innumerable concepts related to this study based on relevant literature. It reviews the various concepts on coastal lagoons, their importance, the influences of human activities on biodiversity, physicochemical parameters, nature of sediments and the role of benthic macroinvertebrates, their distribution as well as factors that affect their abundance.

2.2 Coastal Lagoons

Coastal lagoons are shallow water bodies found between the interface of land and sea. They are separated from the ocean by a barrier, have water depths of only a few meters (usually less than 60 metres) and receives water intermittently from the open ocean by one or more restricted inlets (Kjerfve, 1994). They are significant features in the ecology of the coastal landscape and serve as a transition between sea and land (Basset et al., 2013; Pérez-Ruzafa, Marcos & Pérez-Marcos, 2013). They can also be found on all continents (Clark & O'Connor, 2019; Galliari, Tanjal, del Pilar Alvarez & Carol, 2020; Triest, Beirinckx & Sierens, 2018). Lagoons are among the first ecosystems to have been recognised internationally through the "Convention on Wetlands of International Importance" due to their numerous socio-economic and ecological functions (Davies-Vollum, Zhang & Agyekumhene, 2019; Duku, Mattah & Angnuureng, 2021). Based on how frequently water is exchanged with the ocean, lagoons in Ghana have been divided into open and closed lagoons (Mitchell, Boateng & Couceiro, 2017).

The quality and quantity of water in a lagoon are affected through the rate at which water is lost or gained by groundwater input, precipitation, surface runoff, evaporation and exchange with the ocean (Rajasekar & Philominathan, 2013). Wave and tide actions, which is frequently the greatest part of the balance of water in lagoon, cause water exchange between lagoons and the ocean (Kjerfve, 1994). With 13% of all coastal regions in the globe being coastal lagoons, they are a typical type of coastal ecosystem (Kjerfve, 1994). The assessment of these habitats' natural qualities, particularly their biodiversity, that is one of the key factors used to justify wetland protection regulations, is crucial for their conservation (Mungua & Heinen, 2021).

2.3 Importance of Coastal Lagoons

Lagoons serve as habitats for diverse aquatic organisms, which makes them key sensitive habitats and also environments suitable for human activities (Boateng, Mitchell, Couceiro & Failler, 2020; Ingrosso et al., 2018). Some of these lagoons such as the Keta Lagoon in the Volta Region of Ghana is recognized by the Ramsar Convention as an internationally important wetland because it supports internationally important migrating bird species (Saaman, Annoh & Ireland, 2021). Coastal lagoons also serve as breeding sites, habitat, hiding and resting places for many species, both native and migratory organisms, which make them biodiversity hotspots (Rashid, 2019). Due to this, they serve as one of the major sources of income for people living around them. This sustains artisanal fisheries, which provides a considerable amount of employment and food resources (Mensah & Enu-Kwesi, 2019). In terms of food for the people, it is estimated that, fish that thrive in these coastal environments provide about 70% of all animal protein (Kurien & López Ríos, 2013). In addition, coastal lagoons serve as important feeding and roosting areas for water birds, as well as being used as evaporation ponds for salt production. They provide a number of ecological benefits such as nutrient cycling, supporting biodiversity, and stabilising shorelines thereby protecting coastal areas from storm surges and floods (Newton et al., 2018). They also provide recreational, historical, and aesthetic importance which attracts tourists, thereby boosting the eco-tourism of many countries.

Despite the several socio-economic and ecological benefits, they provide, lagoons are under threat because of the various human activities which influences their quality (Bassi, Kumar, Sharma & Pardha-Saradhi, 2014; Erostate, 2020).

2.4 Human Impacts on Coastal Lagoons

People living around coastal lagoons use them for a number of activities, which includes fishing with various techniques, cutting reeds for thatch and weaving, gathering salt, and irrigating vegetable farms (Newton et al., 2020). These anthropogenic activities have increased the use of the lagoons' resources which, has degraded the ecosystem (Thanh, Tschakert & Hipsey, 2021). Capra and Jakobsen (2017), reported that the quest for economic growth by countries has impacted the ecosystems greatly, as natural resources are overly exploited which has caused these resources to be subjected to constant threats from anthropogenic activities. Again, people living around coastal lagoons depend heavily on them for the provision of their basic needs, including clothes, food, shelter and medicine. As a result, the biodiversity of lagoons is increasingly exposed to anthropogenic pressures (Schooler, 2018). This has caused a global reduction of 30 % in coastal wetlands in the last several decades, including 35 % mangrove cover loss in the last 20 years (Chen & Shih, 2019). The increase in population and demand for ecosystems services have caused degradation of these ecosystems. Human activities usually from urbanization, agriculture, fishery, recreation and industry exert a lot of pressure on coastal lagoons, and introduces contaminants into the water bodies, leading to their deterioration and causing a change in the biological communities (Boanu, 2020). For instance, the Mormugao Harbour's polychaete population changed from carnivores to deposit feeders as a result of increased human activity (Sivadas, Ingole & Nanajkar, 2010).

Essentially, human activities along coastal lagoons reflect the quality and the biological communities of coastal lagoons. Therefore, any pollution in the lagoon environment that affects the organisms will also affect human populations that depend on them. There is therefore a global quest to protect and conserve coastal lagoons for present use and future generations. For example, the World Bank through the Global Environment Facility co-financing was set up in order to support initiatives in Senegal, Tanzania and Guinea-Bissau aimed at safeguarding fish stocks and coastal lagoons (Hewawasam, 2002). In Ghana, a management strategy was formulated for coastal lagoons in 1991(Gordon, Ntiamoa-baidu & Ryan, 2021). It documented the importance of lagoons along the coast of Ghana and the dependence of the local communities on the resources. Despite the effort that has gone into this document, its actions have not been realized, leaving several of the country's lagoons in a deteriorating state (Asmah et al., 2008). The Keta Lagoon does not only serve as feeding and resting grounds for migratory birds as stated earlier. It also serves as breeding nursery and feeding grounds for commercially significant fish species and as well as being a source of finfish and shellfish for human consumption (DeGraft-Johnson, Blay, Nunoo, & Amankwah, 2010; Katano, Hakoyama & Matsuzaki, 2015; Oteng-Yeboah, 1999). Inhabitants within the KLCRS also use water from the lagoon to irrigate their farms. Any pollution in the lagoon will, therefore, have an impact on biodiversity and the people that depend on it.

2.5 Water Quality of Coastal Lagoons

The chemical, physical and biological characteristics of water that make it unsuitable or suitable for use is known as water quality (Wang et al., 2017). The quality of coastal lagoons worldwide is threatened by human activity (Kennish, 2015). The situation has worsened together with effects of climate change.

Non-point and point sources of nutrients discharge of pathogens, and aeolian deposition can cause poor water quality in lagoons (Ongley, 2001). The majority of nitrogen and phosphorus loads in lagoons mainly from domestic and industrial sources, which runoff into the waterbodies can lead to algal blooms and eventually fish kills (Heathwaite, Johnes, & Peters, 1996; Khan &

Mohammad, 2014; Kundu, Coumar, Rajendiran, Rao, & Rao, 2015). Industrial activities and agricultural activities along coastal lagoons can also lead to bad water quality (Affian et al., 2009; Scheren et al., 2004).

The phenomenon of poor water quality has generated increased awareness and interest in the management of the water quality of coastal lagoons (Catianis et al., 2018). Monitoring of physicochemical parameters is one of the ways that water quality of costal lagoons can be managed (Corrales, 1995). The management of physicochemical parameters of waterbodies ultimately control the quality of their biotic component (McCaffrey, 1997; Udoh, Ukpatu & Otoh, 2013). For instance, in aquatic ecosystems, dissolved oxygen (DO) plays a crucial role in determining life's survival. DO in water bodies varies seasonally and daily due to biological activities like decomposition, photosynthesis, respiration and temperature, according to Chapman and Kimstach (1996). Salinity also affects how soluble oxygen is, with high salinity levels leading to a lower level of oxygen (Fondriest Environmental Inc., 2013a). Nitrogen levels are also affected when oxygen levels are low in a lagoon (Zilius et al., 2012) and when the fixed amounts of nitrogen in lagoons decrease, denitrification takes place (Seitzinger & Giblin, 1996). Lagoon stratification and mixing processes regulate anoxic conditions in coastal lagoons (Stein, Gee, Adams, Irving & Van Niekerk, 2021). The lagoon system's biogeochemical processes such as nutrient cycling and decomposition that regulate nutrient fluctuations are impacted by anoxic conditions in the water column, which also have an impact on species and the environments in which they live. The biogeochemical cycles of phosphorus in lagoon sediments can change as a result of altered biogeochemical processes, which further reduce oxygen levels (Viaroli et al., 2005).

Man-made constructions like dams as well as the release of water from these structures can also affect temperature ranges (McCaffrey, 1997). This can affect the rates of development, photosynthesis, metabolism, reproductive success, migration patterns, mobility, aquatic organism life cycles, and vulnerability of organisms to poisons, diseases and parasites (McCaffrey, 1997). Low temperatures (below 10°) can slow down how quickly organisms decompose organic materials (Badu, 2012). Temperature also affects the solubility of dissolved oxygen; high temperature means decreasing solubility of DO (Chapman & Kimstach, 1996).

Conductivity varies between different water bodies. Normal conductivity levels come from surrounding geology. Fresh water generally has low conductivity whereas the ocean has high conductivity levels. Conductivity can be used to determine pollution or the extent to which runoffs have an impact on water bodies (Chapman & Kimstach, 1996). A significant change in conductivity can affect water quality (Fondriest Environmental Inc., 2014a).

Salinity also influences the survival and distribution of organisms in the aquatic ecosystems such as benthic organisms (Cyrus, Vivier, Owen & Jerling, 2010; Lalli & Parsons, 1997). For instance, salinity was found to be one of the elements affecting the distribution of benthic organisms in the Mfolozi-Msunduzi estuarine system on South Africa's southeast coast (Cyrus, Vivier, Owen & Jerling, 2010). Salts are dissolved into water bodies from sources like rural and urban runoff that contains salt, organic materials, and fertilizers

(McCaffrey, 1997). Freshwater generally has low salinity compared to the ocean. This can be due to high dissolved salts in the ocean (Fondriest Environmental Inc., 2014a).

Many chemical and biological processes in water bodies are influenced by hydrogen ion concentration (pH). Hydrogen ion concentration can also be altered generally with rainfall (especially acid rain), effluent and discharges from mining activities (Fondriest Environmental Inc., 2013b). Most organisms in the aquatic environment thrive in a pH range of 6.5 – 9.0 (Kasper, Adeyemo, Becker, Scarfe & Tepper, 2022). Although some organisms can survive outside of the preferred range, a decrease or an increase in pH levels can stress the organisms and also reduce hatching and survival rates. High pH levels can affect organisms and even cause their death. Hydrogen ion concentration also affects how chemicals and heavy metals become soluble and toxic in water bodies (Chapman & Kimstach 1996). The rate of solubility of elements and compounds is usually increased when pH values are low. This increases the likelihood of aquatic life absorbing hazardous chemicals since it makes them more "mobile" (Fondriest Environmental Inc., 2013b). Chapman and Kimstach (1996) stated that changes in pH can be used to indicate that certain contaminants are present, particularly when measured with conductivity.

Phytoplankton is also an excellent indicator of ecological change. They are highly sensitive indicators of nutrient input (Pinckney et al., 2001). Eutrophication is characterized by increased phytoplankton biomass, with the composition of the phytoplankton community becoming more uniform (Guidetti & Danovaro, 2018). The trophic chain typically lacks upper links and autotrophic processes outnumber heterotrophic ones in highly eutrophicated systems, which has a considerable impact on the system's equilibrium (Winder & James, 2010). Studies done by Addo et al. (2014), on the Keta Lagoon’s Trophic Status Index based on estimates of chlorophyll showed that the lagoon was hypereutrophic. According to the authors, the high amounts of nutrients, particularly nitrate (79.44 mg/L - 95.31 mg/L) and phosphate (0.005 mg/L - 0.007 mg/L), which came from farmlands located around the lagoon through leaching, were responsible for the high primary production.

2.6 Pesticides in Coastal Lagoons

Pesticides are among toxic contaminants in the environment as a result of their mobility, stability and long-term impacts on living organisms (Tankiewicz, Fenik, & Biziuk, 2010). Pesticides of many different types have been found in a variety of water bodies including the bottom sediment of coastal lagoons (Martin, Crawford & Larson, 2003; Gilliom, 2001; USEPA, 1997). They can get into surface water and bottom sediment through many ways such as surface runoff, spray drift, drainage systems and contamination via groundwater discharge (Katagi, 2006). These contaminants can change in water, resulting in the production of substances that are considerably more dangerous. In many ways, pesticide contamination of aquatic ecosystems, which support aquatic life and related food chains, presents the greatest risk of unanticipated negative impacts (Gilliom, 2001). The movement of water is one of the main ways that pesticides might spread from specific application regions to different sections of the environment. Therefore, there is a possibility of movement through and into each component of the hydrologic system (Gilliom, 2001).

There are helpful information about pesticides in the hydrologic system, which includes the groundwater, surface water, atmosphere, fluvial sediments, and aquatic biota but there are also significant knowledge gaps that need to be filled (Barbash & Resek, 1996; Larson, Capel & Majewski, 1997; Majewski and Capel, 1995; Nowell, Capel & Dileanis, 1999). For instance, only a small number of pesticides, in particular transformation products, have been thoroughly examined. A lot of data has been gathered for field studies in agricultural settings and small-scale site, while monitoring and research in urban areas have received less attention. Since most research on pesticides use inconsistent methods for data collecting and chemical analysis, comparing and summarizing their findings is challenging (Barbash & Resek, 1996; Larson, Capel & Majewski, 1997; Majewski and Capel, 1995; Nowell, Capel & Dileanis, 1999). Despite years of research into the presence and behaviour of pesticides in the environment, managers of water quality and the general public continue to call for more consistent and thorough information (Lichtenberg & Zimmerman, 1999).

2.7 Sediment Quality of Coastal Lagoons

The quality of the sediment is crucial to coastal lagoons. This can affect the quality of the overlying waters as well as the diversity the benthic community (Kennish & Paerl, 2010). Sediment stability, sediment grain size and organic matter contents are some sediment characteristics that can be used to determine sediment quality and these control the abundance and distribution of benthic macroinvertebrates (Graça, Ferreira, Firmiano, França & Callisto, 2015). Polychaetes for instance, live on the surface of the sediment and depend on the properties of the benthic sediment as well as the quality of the near-bottom water (Musale et al., 2015). For example, very coarse and very fine sand were observed to have few benthic fauna, whereas medium grain-sized silt had a rich fauna in the Swansea Bay (Harkantra, 1982). Benthic organisms depend primarily on organic matter (Badu, 2012). Mainestone and Parr (2002), noted that phosphorus is released into the water column and sediment pore water as a result of the decomposition of organic waste, such as faeces, dead organisms, and leaf litter. Very high (greater than 5%) and low (less than 2%) organic matter content in sediments show less fauna, while midrange levels show rich fauna (Harkantra, 1982). Sedentary polychaetes and amphipods preferred sediment with a high organic matter content, according to Dahanayaka and Aratne's (2010) research. Additionally, excessive organic matter inputs may change the oxygen supply balance in the sediment and water column, which could be detrimental to benthic and fish communities (Badu, 2012). This happens through oxygen being depleted from the breakdown of organic matter (Davies-Colley et al., 1995).

2.8 Biodiversity of Coastal Lagoons

Biological diversity (biodiversity) describes the variety of living organisms found in all environments, including both terrestrial and marine ecosystems (Rees et al., 2018). This involves diversity within and between species, as well as habitats. It is usually used as a proxy for the health of the ecosystem, whereby high biodiversity indicates good health of the ecosystem and less biodiversity indicates poor health of the ecosystem (Bianchelli, Buschi, Danovaro, & Pusceddu, 2018). The vegetation of costal lagoons serves as a specific habitat for a wide range of organisms, including birds and invertebrates, and serves as the foundation for the growth of periphytic communities. They offer aquatic species a haven, food, and substrate (Diehl & Kornijów, 1998). In lagoon ecosystems, the primary limiting factors that determine the environmental niche for benthic macroinvertebrates are water salinity, surface area and outflow length and width (Basset et al., 2006). In coastal lagoons, fish are the predominant nektonic organisms, and their presence is correlated with the salinity of the lagoon and its opening to the sea (Garrido, Pérez-Bilbao & João Benetti, 2011).

Waterfowl and amphibians thrive in lentic environments, and the decline of these creatures is partly attributable to the decline of aquatic ecosystems such coastal lagoons (Garrido, Pérez-Bilbao, & Joo Benetti, 2011). However, they can also be providers of nutrients that have a detrimental impact on eutrophication. Waterfowls are significant consumers in coastal lagoons. Coastal lagoons are home to a variety of vertebrates, including several species of reptiles and mammals in addition to birds, amphibians, and fish (Garrido, Pérez-Bilbao & João Benetti, 2011).

2.9 Benthic Macroinvertebrates in Coastal Lagoons

Benthic macroinvertebrates are organisms without backbones that are between 0.5 and 2.0 mm in size (Bate & Sam-Uket, 2019). They can dwell either on the sediment-water interface or within the sediment and they are vital components of coastal lagoon ecosystems. Benthic macroinvertebrates link primary producers to higher level organisms, which makes them important organisms in the trophic structure of coastal lagoon. They feed on living or decomposed organic matter and serve as food for other vertebrates and invertebrates (Moulton, Magalhães-Fraga, Brito & Barbosa, 2010). Some benthic macroinvertebrates also break down dead animals, plants and waste products (Chesapeake Bay Program, 2018). Benthic macroinvertebrates are also usually used as markers of the biological health of coastal lagoons. Since they spend most of their lives in or on the sediment, they are easy to collect, and have varying levels of pollution tolerance, which makes them reliable indicators (Iyiola, 2020). Benthic macroinvertebrate diversity and abundance in a coastal lagoon are indicators of the biological health of the ecosystem. Coastal lagoons generally support majority of macroinvertebrate taxa, including many that are pollution intolerant, in healthy biological conditions. A less healthy system may be indicated by sediment samples that contain mostly species that can tolerate pollution or by very little diversity or abundance.

The most comprehensive way to determine the health of an aquatic ecosystem is its biological state (Saad Abdelkarim, 2020). When the biology of a lagoon is healthy, the physical and chemical components are also usually in good state (Barhoumi et al., 2016). For instance, Aggrey-Fynn et al. (2011) opined that a change or deterioration in the environmental conditions of lagoons could result in reduction in composition, richness and diversity of benthic macroinvertebrates. A separate study by Lamptey and Armah (2008) on benthic macroinvertebrates in the Keta Lagoon reported low density and species diversity. Salinity, pH, and turbidity are known to be the main significant physicochemical variables that structures the macrobenthic faunal population in the Keta Lagoon (Aggrey-Fynn et al., 2011).

CHAPTER THREE

MATERIALS AND METHODS

This chapter discusses the profile of the lagoon studied in terms of location, geology, hydrology and economic activities. Detailed description of the techniques for collecting data on physicochemical parameters, nutrients, sediments, pesticides, chlorophyll-*a* and benthic macroinvertebrates are also provided here in addition to data analyses.

3.1 Study Area

The study was carried out in the Keta Lagoon Complex Ramsar Site (KLCRS), located in the southern part of Volta Region (Tufour, 1999), between latitudes 05°55'N and 00°49'E. It is bordered on the West by the Volta River, in the South by the Gulf of Guinea and in the North by the highway that links Accra (capital of Ghana) to Lome. The KLCRS is a lagoon with brackish water, flood plain, marshland and wide range of mangrove stands (Lamptey et al., 2013). The open water of the lagoon and wetlands associated with it covers an area of about 702 km^2 (Xorse, 2013). The lagoon covers an estimated surface area of 340 km^2 with average water depths which ranges from 0.47 m to 0.94 m during the wet season and 0.14 m to 0.56 m in the dry season (Lamptey & Armah, 2008). The maximum width and length of the lagoon is approximately 25 km and 13.5 km respectively (Lamptey & Armah, 2008). The lagoon and its catchment forms part of the extensive Volta delta system, which has been defined as the land below the 5 m contour (Addo et al., 2018). Streamflow of the lagoon corresponds to the seasonal variation in rainfall (Agyare et al., 2015). It was designated as a Ramsar site in 1992 (Kumi, Kumi & Apraku, 2015). The

KLCRS is important for its socio-economic and ecological activities. The main livelihoods of individuals who reside in the southern sector of the lagoon are sea and lagoon fishing, salt mining, and farming, whereas those who reside in the northern sections are primarily farmers with some freshwater fishing in the areas along the channel and rivers. The lagoon is surrounded by about 16 communities.

Five communities within the Ramsar Sites were selected for the study, namely Anloga, Havedzi, Tegbi, Atiavi and Fiaxor. These communities were selected based on their predominant economic activities. Anloga represents fishing community while Havedzi, Tegbi and Atiavi represent salt mining, farming and cottage weaving communities respectively. Fiaxor was selected as reference site because the people preferred going to other communities for their work which made activities in the community less.

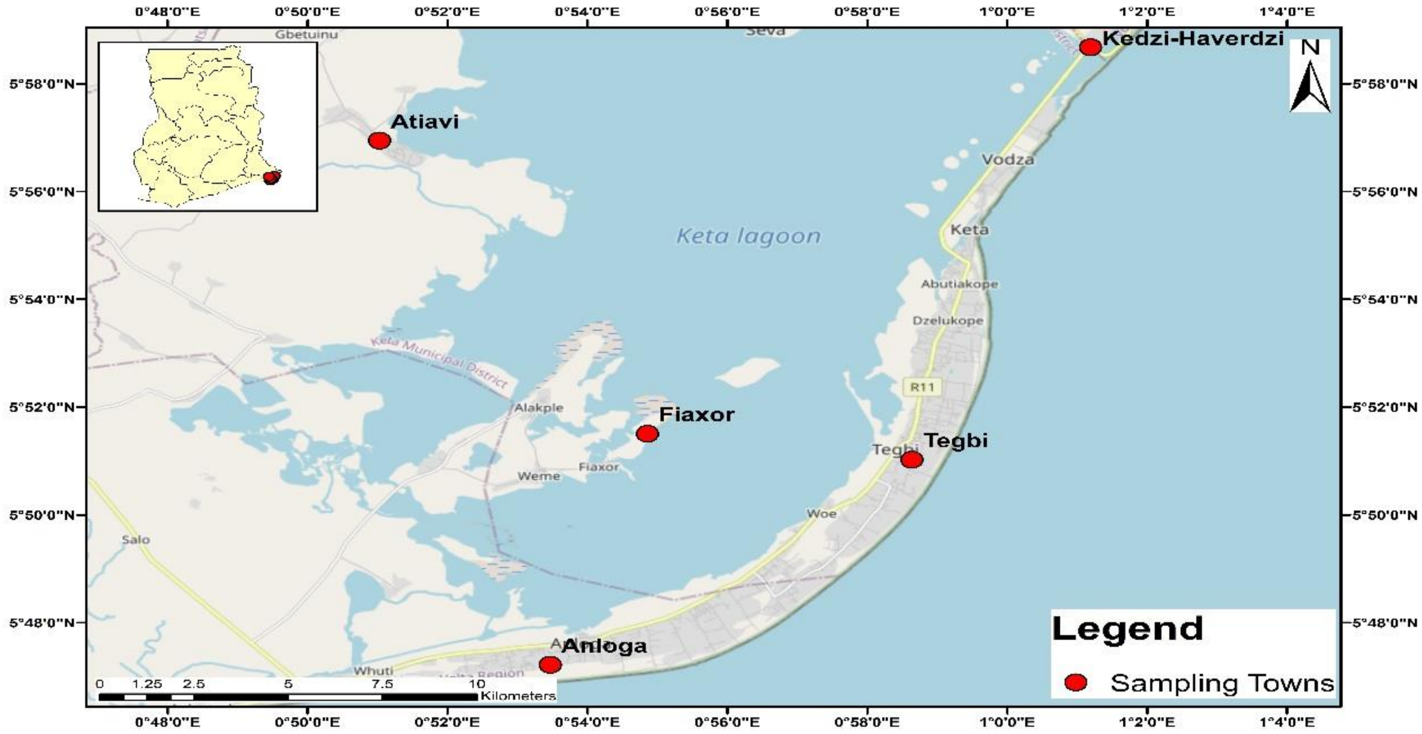

Figure 1: Map of the Keta Lagoon Complex Ramsar Site showing sampling communities

Source: Author

3.2 Sampling Period and Locations

For six months, sampling was done monthly (January, February, March, May, June and July, 2022) The stratified sampling strategy was utilized in this study. Each site represented by a community was divided into stations so as to get a representative sample size and each station had three replicates. Three sampling stations were marked in each community to represent the lower-stream, middle-stream and upper-stream of the lagoon where samples were taken.

3.3 Data Collection

Data on some physicochemical parameters (pH, salinity, dissolved oxygen (DO), total dissolved solids (TDS), conductivity, and temperature), chlorophyll-*a*, sediment particle sizes and organic matter, pesticides and nutrients were collected in triplicates from each station. Physicochemical parameters were measured *in situ* with a multiparameter probe (section 3.3.1). Water, sediment and periphyton samples, were collected with sampling bottles and sent to the laboratory for other analyses. The procedure in section 3.3.3 was used to determine phosphate and nitrate concentrations in both the water and sediment samples. Chlorophyl-*a* concentration was also determined in the periphyton and water samples. Mean particle sizes and organic matter content were determined in the sediment samples in the laboratory using a standard protocol. Pesticides concentrations were also determined in both sediment and water samples. Benthic macroinvertebrates were collected from separate sediment samples which were screened to collect the organisms. All the parameters (both biotic and abiotic) were analysed for all the months except pesticides which were analysed for only two months; February for dry season and June for wet season.

3.3.1 Physicochemical parameters

Physicochemical parameters namely total dissolved solids (TDS), dissolved oxygen (DO), salinity, conductivity, temperature and pH were measured *in situ* using a multi-parametric water quality checker (HORIBA, U-5000 JAPAN) in the morning. The probe was lowered to the bottom of the lagoon and the readings taken. Turbidity was also taken with a turbidimeter. At each station in each community, triplicate measurements were taken during every sampling period. The triplicate measurements were taken by dividing each station into three points to cover the length of the lagoon.

3.3.2 Chlorophyll-*a* concentration

Water samples (250 ml) were collected into 250 ml plastic bottles and kept in black polyethene bags to avoid photosynthesis. The samples were sent to the laboratory on ice to be refrigerated at 4 °C. The samples were gently mixed and filtered through a glass microfiber filters (by CHMLAB GROUP, 1.2 micron). The filters were placed on a filter holder using forceps and samples were filtered using the filter pump. The filter paper was removed carefully from the filter with forceps and kept in cleaned labelled specimen vial. Extraction of the chlorophyll-*a* pigment was carried out by soaking the filter paper in 5 ml of 95% ethanol and stored at 4 °C for 24 hours. The sample extracted (5 ml) was carefully poured into a cuvette and the chlorophyll-*a* concentration was measured using a fluorometer and recorded (in ug/L).

3.3.3 Nitrate and phosphate determination

Water samples (250 ml) were collected into 250 ml plastic bottles and kept on ice. Sediment samples were also collected into ziplock® bags and also kept on ice and brought to the laboratory. With the aid of HACH reagents, a pre-calibrated multi-parametric spectrophotometer (HACH DR 900) was used to measure nitrate and phosphate levels. Water samples were allowed to warm up to room temperature before the analysis. For nitrate analysis, a powder pillow of NitraVer 5 reagent was used. One (1) powder pillow of nitrateVer5 reagent was added to ten (10) ml of the samples in a specimen vial. The sample was agitated for 1 minute, then let to stand for 5 minutes. Distilled water was also used to prepare a blank sample, 10 ml was poured into another specimen vial. This was used to check for contamination during preparation of samples. The blank was put into the cell holder and the equipment lid was used to cover it. NO_3^--N was selected on the spectrophotometer and zeroed. Thereafter, the samples were placed in the cell holder and carefully covered with the equipment cap, the readings were taken in under 2 minutes. NO_3^- was calculated from NO_3^--N by multiplying the value gotten by 4.427 (Dzakpasu, 2019; Fadiran & Mamba, 2005). The same process that was used for the nitrate analysis was used for the phosphate analysis except that, PhosVer 3 powder pillow was used for phosphate concentration. The sample was shaken vigorously for 30 seconds and let to stand for 2 minutes. On the spectrophotometer, PO_4^{3-} was selected and readings were taken in under 2 minutes.

Air dried sediment samples were used for the analysis. The samples were air dried for a period of 72 hours to 120 hours, depending on how muddy the was. In a round-bottom flask, fifteen (15) grams of dried sample and 0.15 g of calcium sulphate were placed. A 20-ml volume of distilled water was added to the mixture in the round-bottom flask, which was then capped and stirred for one minute. The bottle's content was filtered (using Whatman filter paper) into a beaker and the concentration of nitrate was determined using the filtered extract. A powder pillow of NitraVer 5 Nitrate reagent was put to a specimen vial together with 10 ml of the calcium sulphate extract and the same procedure described for the water analysis was followed. Ten millilitres (10 ml) of the extract was poured into another specimen vial, which was used as the blank solution.

For the phosphate concentration determination, 180 ml of distilled water was poured into a container and 20 ml of Mehlich 2 soil extractant concentrate was added and mixed thoroughly. A round-bottom flask was filled with 20 ml of the diluted Mehlich 2 extractant and 2 g of the dried sediment sample. The mixture was agitated for five minutes, filtered (using Whatman filter paper) in a beaker and used. Using a measuring cylinder, 2. 5 ml of the extract and 22.5 ml of distilled water were measured into a beaker and mixed. Ten millilitres (10 ml) of the solution was poured into a specimen vial and powder pillow of PhosVer 3 reagent was added, and the same procedure for the water analysis was followed and the reading taken. Ten millilitres (10 ml) of the extract was poured into another specimen vial and this served as the blank.

3.3.4 Biological oxygen demand (BOD) determination

The probe method was employed for the BOD determination (Jouanneau et al., 2014). Water samples were collected into BOD bottles. The initial oxygen concentration of the samples was taken with a water quality checker and the samples were transported to the lab. They were incubated for five days and the final oxygen concentration taken on the fifth day using the same water quality checker. The BOD was determined using the equation below;

$$BOD= (IOC) - (FOC)$$

where;

IOC= Initial Oxygen Concentration

FOC= Final Oxygen Concentration

3.3.5 Pesticides analysis

Pesticides were determined in both water and sediment samples in Ghana Standard Authority pesticides laboratory. Replicates from each station was composited into one sample making the samples three in each community (site) (one each from lower stream, midstream and upper stream). Water samples were collected into 500 ml plastic bottles and sediment samples were collected into ziplock rubbers. The samples were kept on ice and brought to the laboratory.

Water samples for pesticides were filtered through a filter paper (using Whatman filter paper) to remove debris and solid particles. Thirty millilitres (30 ml) of saturated sodium chloride solution was added after one litre (1L) of the sample was measured (replicates from each station was composited to get the 1L) and placed into a separatory funnel with a capacity of 2 L. The sample was separated with 100 ml of dichloromethane by shaking the separatory funnel containing the sample vigorously for 2-3 minutes and intermittently releasing the pressure. The layers were separated and the dichloromethane extract layer was drained into a 500 ml round bottom flask. The partitioning process was repeated two more times and the organic phase was collected each time into the round bottom flask. The partitioning was done with a filter paper containing a sufficient amount of sodium sulphate in order to trap moisture that may have drained with the organic phase. The three dichloromethane layer extracts were mixed and concentrated to a volume of about 2 ml using a rotary vacuum evaporator below 40°C which was used for gas chromatography analysis. A 1000 mg/ml Silica cartridge with 0.3 g layer of sodium sulphate was conditioned with 10 ml of dichloromethane. It was filled with the sample extract, and 100 ml round-bottom flask was used to collect the elute. Dichloromethane (20 ml) was used to elute the column, and the eluent that was recovered was concentrated using a rotary evaporator at a temperature below 40 °C to achieve dryness. The nearly dry sample extract was then redissolved in 1 ml of ethyl acetate and put into a 2 ml vial with a standard opening for GC-ECD and GC-PFPD quantification. For quantification by GC-ECD and GC-PFPD, 20 uL of 1% poly ethylene glycol was placed into a 2 ml, standard opening vial and mixed with ethyl acetate (v/v).

Sediment samples were comminuted and homogenized and 10g was weighed and poured into a 100 ml separating flask. Ten millilitres (10ml) of acetonitrile was added to it. The separating flask was corked and shaken for 2 min. Another 10 ml of acetonitrile was added, and it was shaken constantly for 30 minutes on a horizontal mechanical shaker. The layers were separated by allowing the mixture to stand for 10 minutes. Ten millilitres (10 ml) of the aliquot of the organic phase (top layer) was pipetted into a 50ml round-bottomed flask and concentrated to about 2 ml using a rotary vacuum evaporator below 40°C for extract purification. The extract was placed onto a "Silica" (1000 mg/ml) cartridge that has a 1 cm layer of anhydrous magnesium sulphate on top that was conditioned with (10 ± 0.2 ml) of acetonitrile. The column was eluted with 20 ml acetonitrile and concentrated using a rotary evaporator at a temperature below 40°C just to reach dryness after collecting the eluent into a 50 ml pear-shaped flask. It was then redissolved in 1 ml of ethyl acetate and mixed with 20 µL of 1% polyethylene glycol. The extract was placed into a 2 mL standard opening vial before quantified by GC-ECD and GC-PFPD.

3.4.5 Sediment mean particle size (MPS) analysis

Sediment samples were air-dried, put into pre-weighed aluminium bowls and dried at 105 °C in an oven until a steady weight was attained. A set of sieves with various mesh sizes (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.0625 mm) and a collector (pan) at the bottom was used to sieve 100 grams (g) of dried sediment. Samples collected in each sieve was gathered, weighed, and recorded. The particles that were smaller than the mesh sizes were collected in the pan. The weight of sediment collected on each sieve was determined as a percentage of the original soil sample used as shown in the equation:

$$\text{Composition of sieve content (\%)} = \frac{\text{Weight of sieve content}}{\text{Weight of dry sample}} \times 100$$

Knowing the percentage compositions of the various sieve contents, mean particle sizes (MPS) were calculated using:

$$\text{MPS} = \frac{\Sigma(\bar{x}.\text{Y})}{100}$$

where, $\bar{x}$ = mean size of the soil separates (mm) and Y = corresponding percentage composition. Mean particle sizes calculated for were compared to the Wentworth classification of particle grades as given in Table 1. This was used to determine the corresponding particle grade size.

Table 1: Wentworth classification of particle grades and phi scale

Grade name	Particle size range (mm)	Particle size range (Phi units)
Boulder	> 256	Beyond – 8.0
Cobble	256 → 64	-8.0 → -6.0
Pebble	64 → 4	-6.0 → -2.0
Granule	4 → 2	-2.0 → -1.0
Very coarse sand	2 →1	-1.0 → 0
Coarse sand	1 → 0.5	0 → 1.0
Medium sand	0.5 → 0.25	1.0 → 2.0
Fine sand	0.25 → 0.125	2.0 → 3.0
Very fine sand	0.125 → 0.0625	3.0 → 4.0
Silt	0.0625 → 0.0039	4.0 → 8.0
Clay	< 0.0039	Beyond 8.0

3.4.6 Sediment organic matter (OM) content determination

At a temperature of 105 °C, sediment samples were oven-dried to a consistent weight. Where necessary, debris were taken out of the dried sediments, and they were sieved through a 2 mm sieve. Hundred grams (100 g) of the dried and sieved sediment was put in a furnace to burn off the organic matter at 550 °C for 4 hours. The samples were placed in a desiccator to cool. The samples were weighed upon cooling and the loss in weight was recorded as “weight loss on ignition”. The percentage organic matter content was calculated using the equation:

$$\text{OM content (\%)} = \frac{\text{Weight loss on ignition (g)}}{\text{Weight of dry soil (g)}} \times 100$$

3.4.7 Benthic macroinvertebrates

Benthic macroinvertebrates were collected using an Ekman grab and sediment samples were washed. Samples retained on a 0.5 mm mesh size were stored in containers and preserved with 10% formalin and Rose bengal was used to stain the organisms to aid sorting. Samples were washed thoroughly with water and spread evenly on a sorting tray, with a white background in the laboratory. Benthic organisms were picked using a forceps and placed into storage vials containing 10% formalin for preservation. Organisms picked were identified to the lowest possible taxonomic level under a dissecting microscope (x10 magnification) with the aid of identification manuals (Ardovini & Cossignani 2004; Al-yamani et al., 2012; Rouse & Pleijel, 2021; Edmunds, 1978; Yankson & Kendall, 2001).

Ecological indices namely species diversity, evenness and richness were computed for the various communities as follows:

Margalef's index was adopted for the calculation of species richness using the equation (d) = $\frac{s-1}{In(N)}$

where s is the number of species in a sample and N is the total number of individuals in the sample.

Species diversity was calculated using Shannon-Wiener's index (H');

$$(H') = -\sum_{i=1}^{s}\left(P\iota(InP\iota)\right)$$

where s is the number of species, Pι is the Proportion or the number of individuals of one species in relation to the number of individuals in the population.

Pielou's index (J') was also adopted for the calculation of species evenness by using the equation

$$(J') = \frac{H'}{\ln(s)}$$

where s is the number of species and H' is the Shannon-Wiener diversity index.

3.5 Data Analysis

The parameters studied in the five communities were analysed using different statistical methods. Means ± SD were calculated monthly for each parameter and community. Microsoft Office Excel, Minitab and SPSS version 26 software were used for the analyses.

For each of the parameter, one-way analysis of variance (ANOVA) was used to test for significant differences across the communities, and the months. Where significant differences occurred, Tukey's post hoc tests were performed to confirm where the differences occurred. For benthic macroinvertebrates, ecological indices were calculated for each community (site) by counting the number of species. Percentage compositions were computed for organisms that occurred most in each of the communities.

Canonical Correlation Analysis (CCA) was used to predict the relationship between the physicochemical parameters, sediment parameters and benthic macroinvertebrates abundance. This analysis was found suitable because the analysis allows a direct comparison of abiotic data and species diversity. It seeks to identify and quantify the associations between two sets of variables. In this case, the environmental and the benthic macroinvertebrates variables. All statistical decisions were made at 0.05 alpha value. The results were presented in tables, bar graphs and line graphs showing trends of values for the months.

3.6 Chapter Summary

This chapter gives information on the Keta Lagoon. Sampling procedures were also discussed here. To confirm that sample sizes were representative enough and to prevent sampling errors, samples and measurements were taken in replicates throughout the study. Pesticides analysis was done at Ghana Standards Authority (GSA). To ensure the accuracy of the data collected, quality assurance procedures were put in place. This chapter described the appropriate statistical analyses that were used to make reliable inferences and also to make it simple to compare results across communities and months.

CHAPTER FOUR

RESULTS

Findings made from the study, which includes the biodiversity and abundance of benthic macroinvertebrate community, water quality parameters, sediment quality and the relationship between all these parameters have been organised and presented in this chapter. The results are presented under various sections. Sampling periods are denoted by January, February and March representing the dry season, while May, June and July representing the wet season.

4.1 Water Quality Parameters in the Five Communities

Variations in salinity, DO, conductivity, temperature, turbidity, pH, TDS, BOD, nitrates, phosphates and chlorophyll-*a* in each of the communities during the study period are presented in figures. ANOVA at 95 % confidence interval was used to test for the differences across the communities and months and where applicable (Appendix A), Tukey's post hoc tests also showed where the specific differences were (Appendix B).

4.1.1. Temperature

There were temporal variations in temperatures in all the communities, with the highest temperature reported in March and the lowest in July (figure 2). Values across communities and months were statistically significant ($p < 0.05$). The post hoc test showed Tegbi had the lowest value in July (25.52°C) and Havedzi recorded the highest value in March (33.61°C). In general, values were relatively lower in the last 3 months as compared to the first 3 months in all the communities.

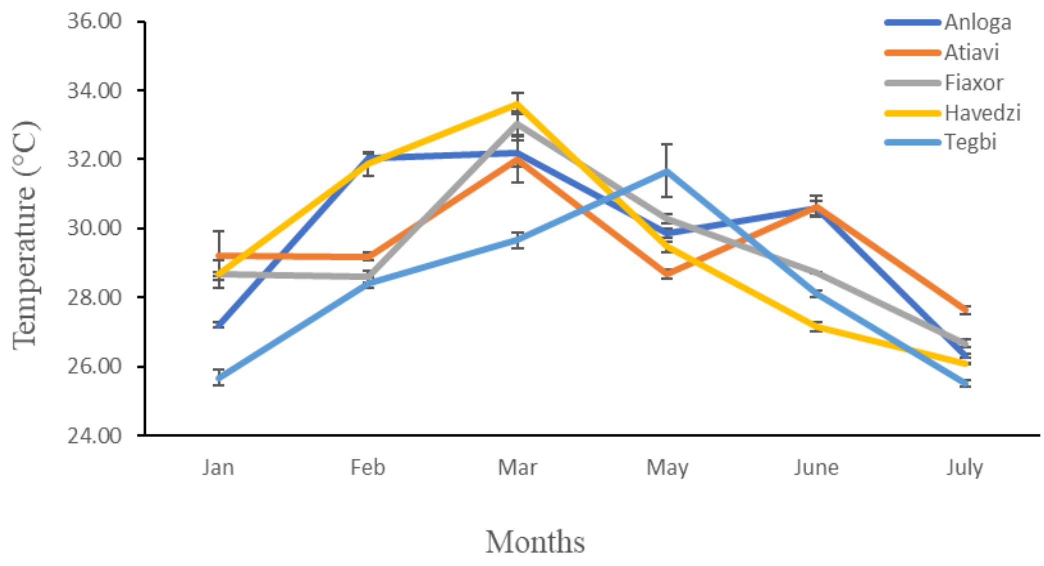

Figure 2: Monthly variations in temperature in the five communities

4.1.2. Salinity

Salinity was generally high with values from 21.50 to 32.21 ppt. There were no significant differences recorded across the sampling communities. However, there were significance difference across the months with the highest value reported in March and lowest value recoded in July (Figure 3).

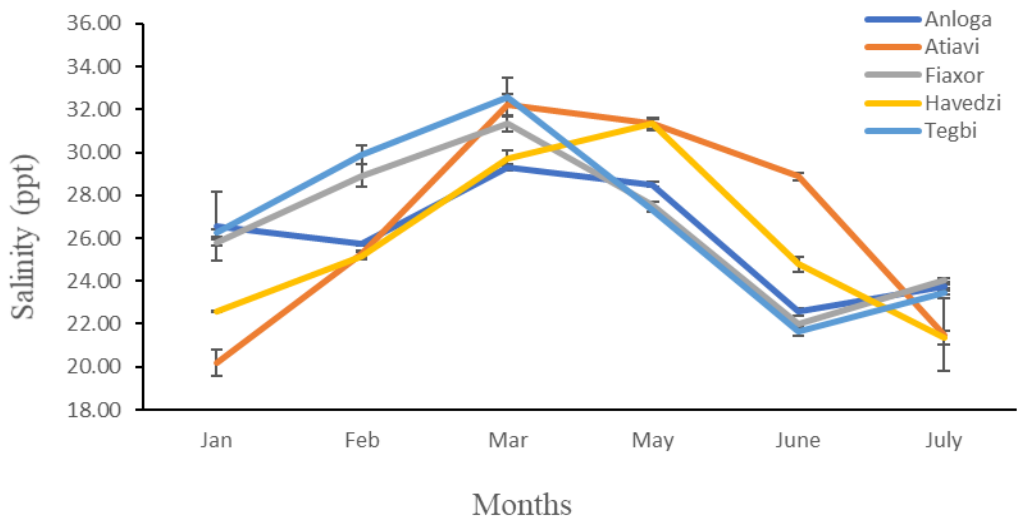

Figure 3: Monthly variations in salinity in the five communities

4.1.3 Conductivity

Conductivity values were between 32 µS/cm and 49 µS/cm for the sampling communities. There were no significant variations across the communities. However, significant values were recoded across the months, with the highest value occurring in March and the lowest value occurring in January (Figure. 4).

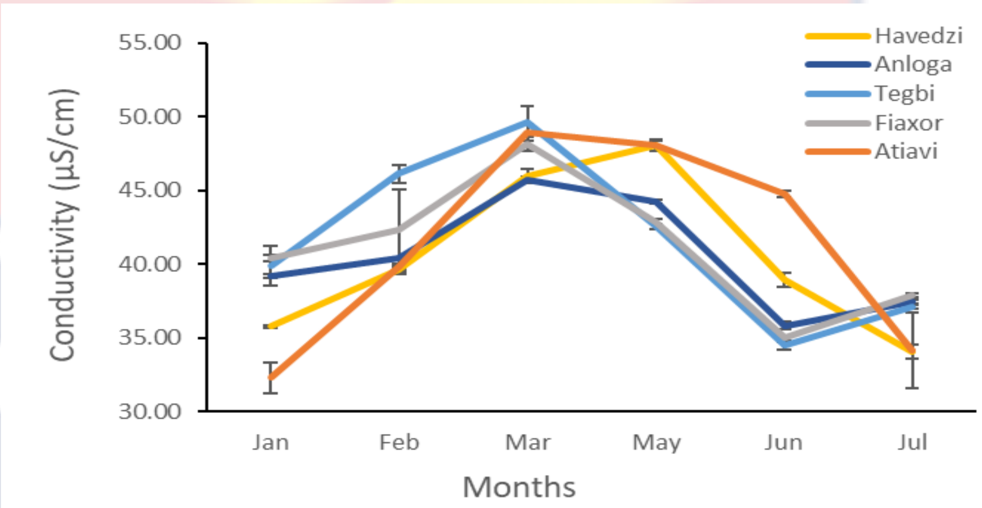

Figure 4: Monthly variations in conductivity in the five communities

4.1.4 Dissolved oxygen (DO) concentration

Figure 5 shows the monthly mean DO variations for the sampling communities. DO concentrations ranged from 4.00 – 8.70 mg/l. The values fluctuated throughout the months for all the sampling communities. However, the highest value occurred in January and the lowest value in May. There were significant differences at $p < 0.05$ between the values across the sampling communities and sampling months. Mean DO ranges obtained were 4.65– 8.04 mg/l, 4.08– 7.35 mg/l, 5.38 – 8.64 mg/l, 4.57 – 7.59 mg/l, and 4.04 – 6.71 mg/l for Havedzi, Anloga, Tegbi, Fiaxor and Atiavi respectively. However, Atiavi recoded no values in January since DO meter in the probe broke down during sampling at the time.

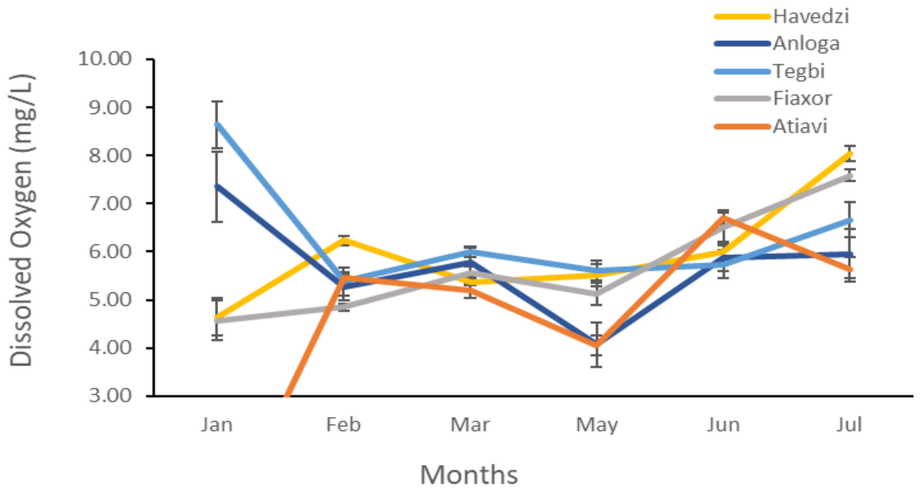

Figure 5: Monthly variations in DO in the five communities

4.1.5 Hydrogen ion concentration (pH)

Values of pH were generally low (< 6.5) in the last 2 sampling months. Figure 6 shows a decrease in values from January to July for all the five communities. Variations were not statistically significant across the communities but were different across the sampling months at $p < 0.05$, with the highest value recoded in January and the lowest value in July.

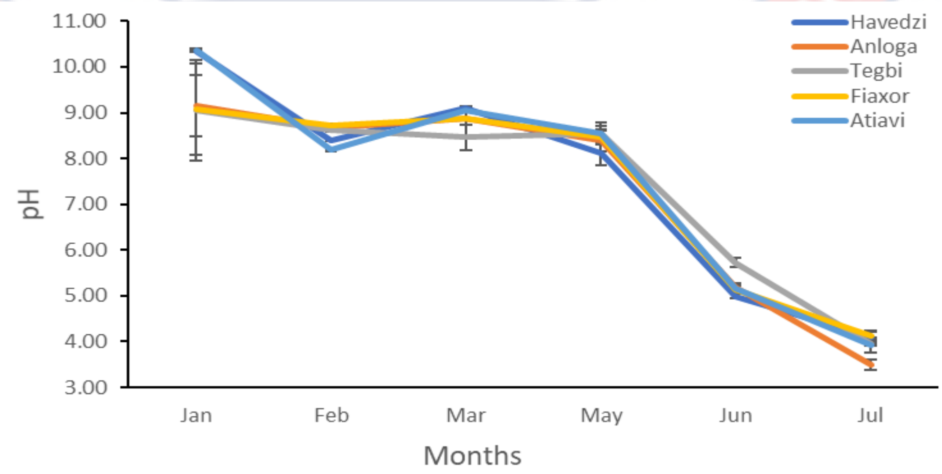

Figure 6: Monthly variations in pH in the five communities

4.1.6 Turbidity

Turbidity values were fairly lower in Havedzi (2.42 – 11.67 NTU) and Fiaxor (1.89 – 17.00 NTU) throughout the sampling months compared to the other three communities (Figure 7). Differences in turbidity across sampling communities and months were statistically significant ($p < 0.05$). Post hoc confirmed Atiavi and Anloga had significantly higher turbidity values while Havedzi and Fiaxor had lower turbidity. Also, the highest value was recoded in March while the lowest value was recorded in June.

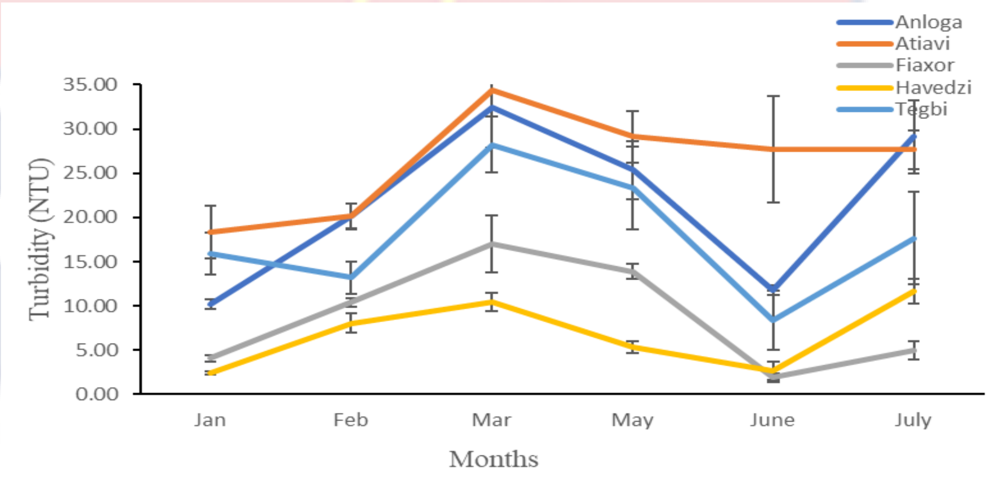

Figure 7: Monthly variations in turbidity in the communities

4.1.7 Total dissolved solids (TDS)

Mean TDS values were fairly high ranging from 20.95 g/L to 30.09 g/L in all the five communities. There were no significant differences across sampling communities but there were statistical differences within the sampling months, with the highest value being recorded in March and the lowest values recoded in January (Figure 8).

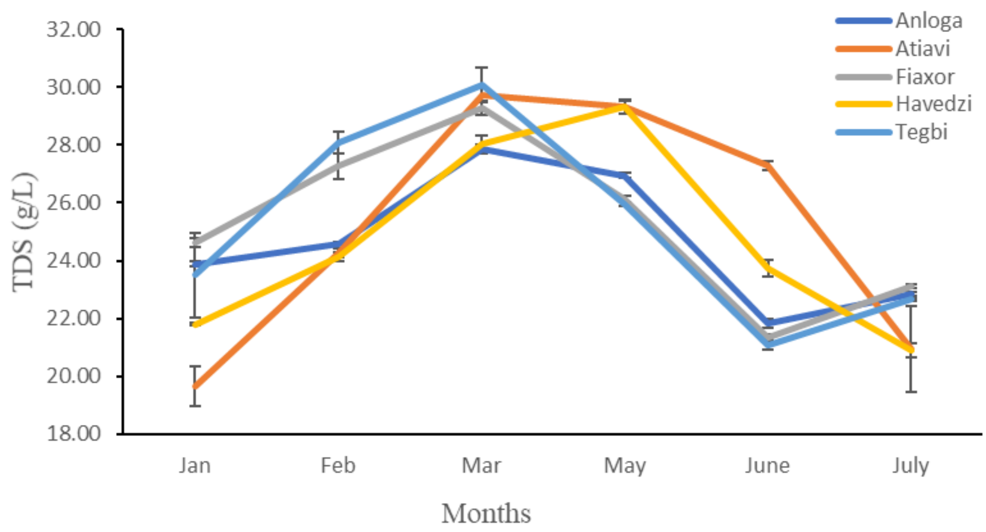

Figure 8: Monthly variations in TDS in the five communities

4.1.8 Chlorophyll-*a* concentration

Chlorophyll-*a* concentration was comparatively lower in February and higher in March for all the sampling communities. Mean values recorded were from 2.05 ug/L to 7.87 ug/L. There were significant differences across the sampling communities and months. Atiavi recorded the highest value and Havedzi recorded the lowest value. The lowest value occured in January while the highest value occured in March (Figure 9).

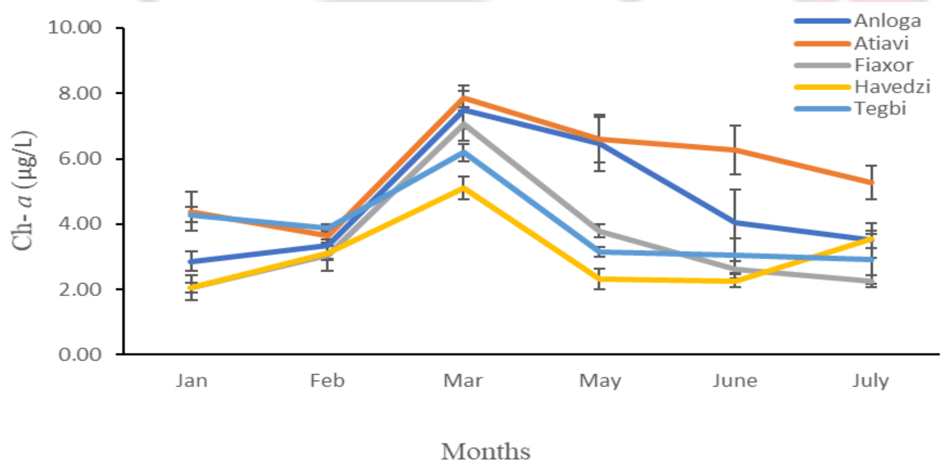

Figure 9: Monthly variations in chlorophyll-*a* in the five communities

4.1.9 Biological oxygen demand (BOD)

Biological oxygen demand values were relatively higher during the last three (3) sampling months (May, June, July). Highest mean value recorded was 2.57 mg/L at Fiaxor in July whereas the lowest value recorded was 1.04 mg/L at Havedzi in July (figure 10). There were no statistical differences across the sampling communities but there were statistical differences recorded within the sampling months. However, there were no values recorded in January because no samples were collected for BOD analysis.

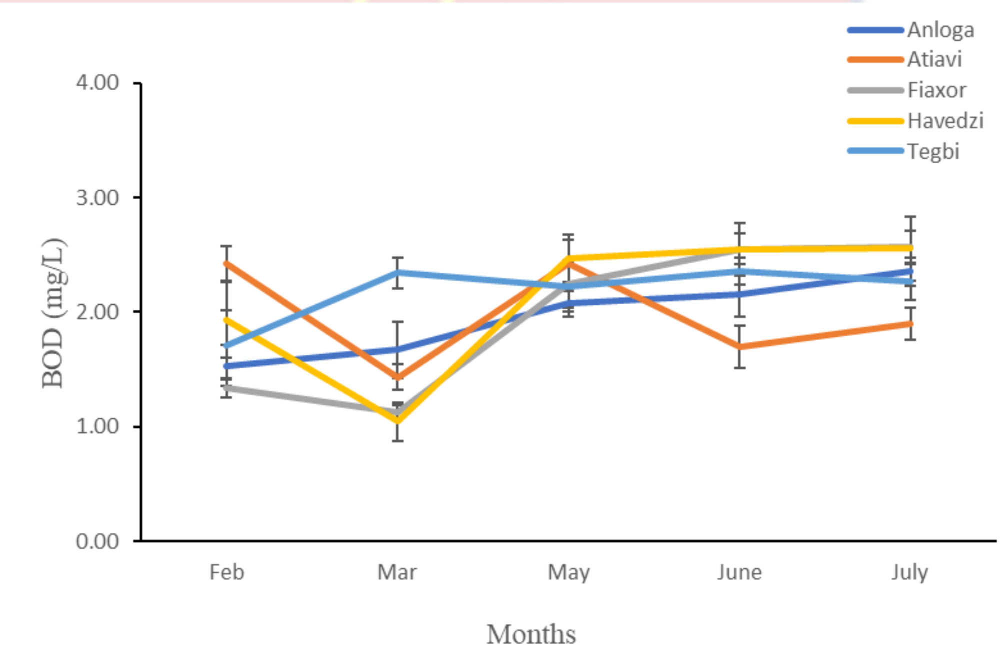

Figure 10: Monthly variations in BOD in the five communities

4.2 Nutrients Concentrations

This section covers monthly variations in nitrate and phosphate concentrations in both water (Figures 11 and 12) and sediment (Figures 13 and 14) in all the sampling communities. ANOVA at 95 % confidence interval showed the differences in the parameters across the sampling communities and months and Tukey's post hoc tests also showed communities and months were different.

4.2.1 Nitrate

Mean nitrate values were generally < 20 mg/L in both water and sediment in most of the sampling communities. Mean nitrate values recorded in water was 4.13 mg/L – 23.27 mg/L (figure 11). There were statistical differences within the sampling communities and months. The highest value occurred in March and it was recorded in Atiavi. The lowest value also occurred in January and was recorded in Havedzi. For the sediment, the mean nitrate value recorded was 3.39 mg/L – 24.45mg/L (figure 12). There were statistical differences within the sampling communities and months ($p < 0.05$). The highest value was recorded in March and it was recorded in Fiaxor. Tegbi also had the lowest reading, which was observed in February.

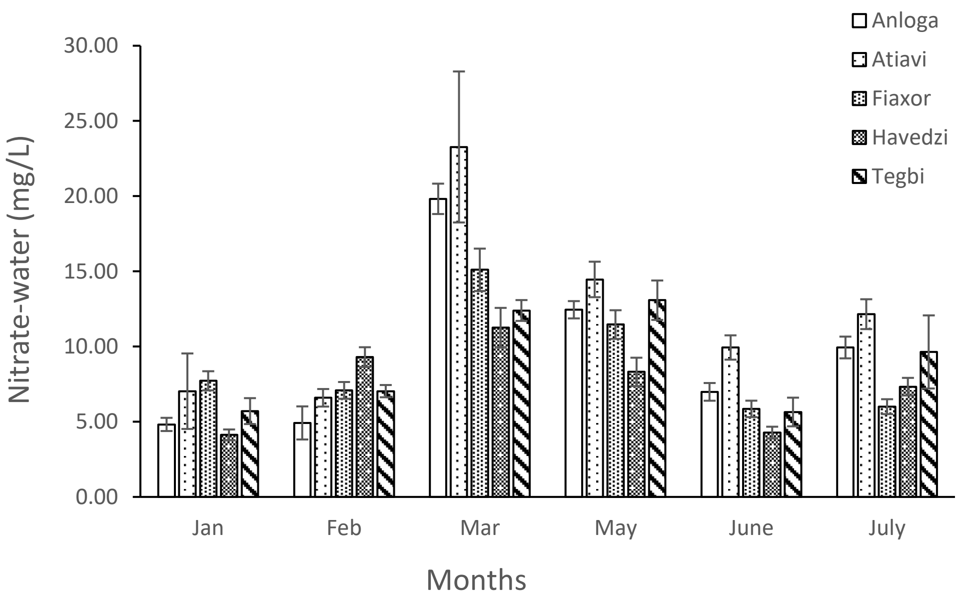

Figure 11: Monthly variations in nitrates in water in the five communities

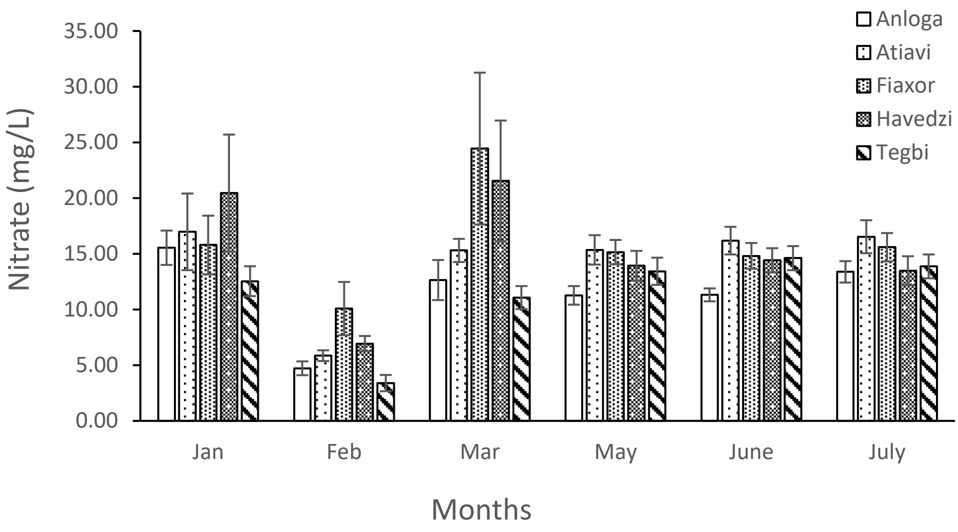

Figure 12: Monthly variations in nitrates in sediment in the five communities

4.2.2 Phosphate

Mean phosphate values were generally < 2.0 mg/L in both water and sediment in most of the sampling communities. Mean phosphate values in water recoded was 0.14 mg/L – 6.06 mg/L. There were no statistical differences within the sampling communities. However, Atiavi had the highest value and Fiaxor had the lowest value (figure 13). There were statistical differences across the sampling months. The highest value was reported in June and the lowest value occurred in July. For the sediment, the mean phosphate values recorded was 0.25 mg/L – 3.60 mg/L. There were no statistical differences within both the sampling communities and months. However, the highest value was recorded in July and it was recorded in Fiaxor. February also recorded the lowest value, which was in Tegbi (figure 14).

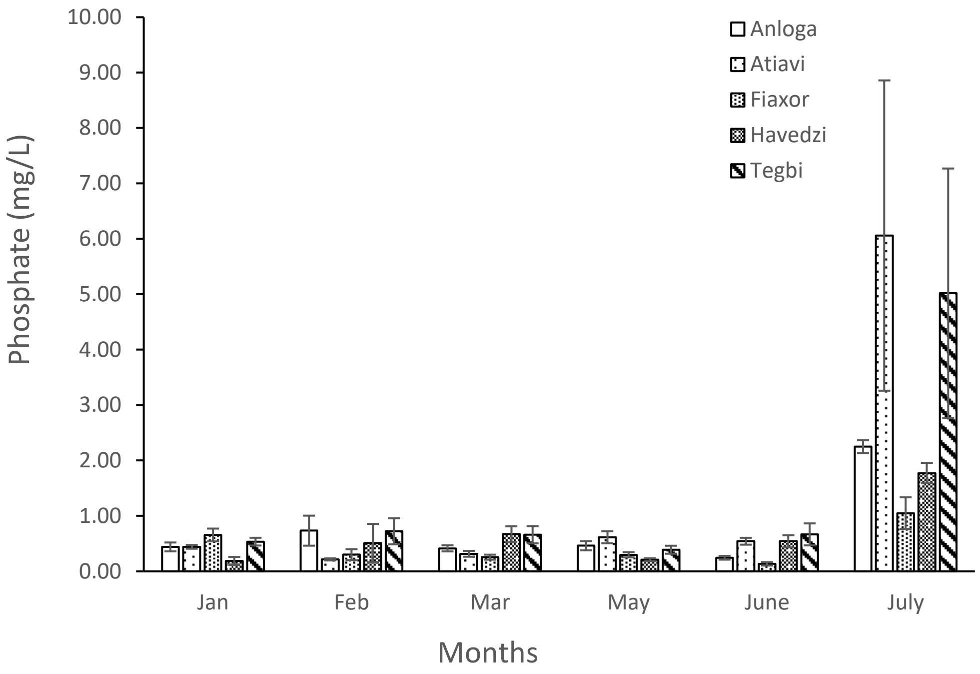

Figure 13: Monthly variations in phosphates in water in the five communities

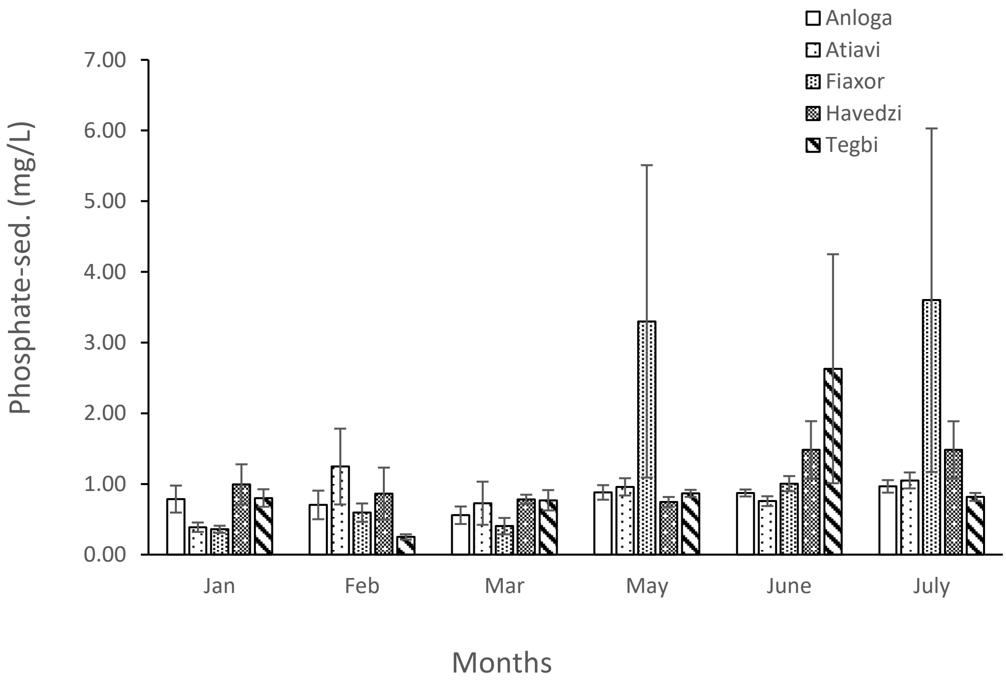

Figure 14: Monthly variations in phosphates in sediment in the five communities

4.3 Pesticides concentrations

Chlorpyrifos, Lambda-cyhalothrin and Primiphos-metthyl pesticides residue were detected in the water column at Anloga, Fiaxor, Tegbi and Havedzi (Table 2). A number of pesticides residue (Appendix E) were analysed for but were not detected in the water body. The analysis was done in February and June.

Table 2: PESTICIDES residue and concentrations detected

	February			June	
Pesticides detected	**Anloga**	**Tegbi**	**Fiaxor**	**Havedzi**	**LOQ**
Chlorpyrifos µg/L	0.20	-	0.10	-	0.05
Lambda-cyhalothrin µg/L	-	0.20	-	-	0.05
Primiphos-methyl µg/L	-		-	0.20	0.05

*LOQ denotes level of quantification

4.4 Sediment Parameters

This section describes the mean sediment particle size and the organic matter content of the sediment in all the sampling communities during the study period. Statistical output for the and Tukey's post hoc test are presented in Appendix C and Appendix D respectively.

4.4.1 Organic matter content

Mean organic matter content ranged from 1.32 to 6.98 % in all sampling communities (Figure 15). There were no significant differences across the sampling communities. Fiaxor had lower organic matter content than Anloga, which had the highest organic matter content. Monthly variations were, however, not different.

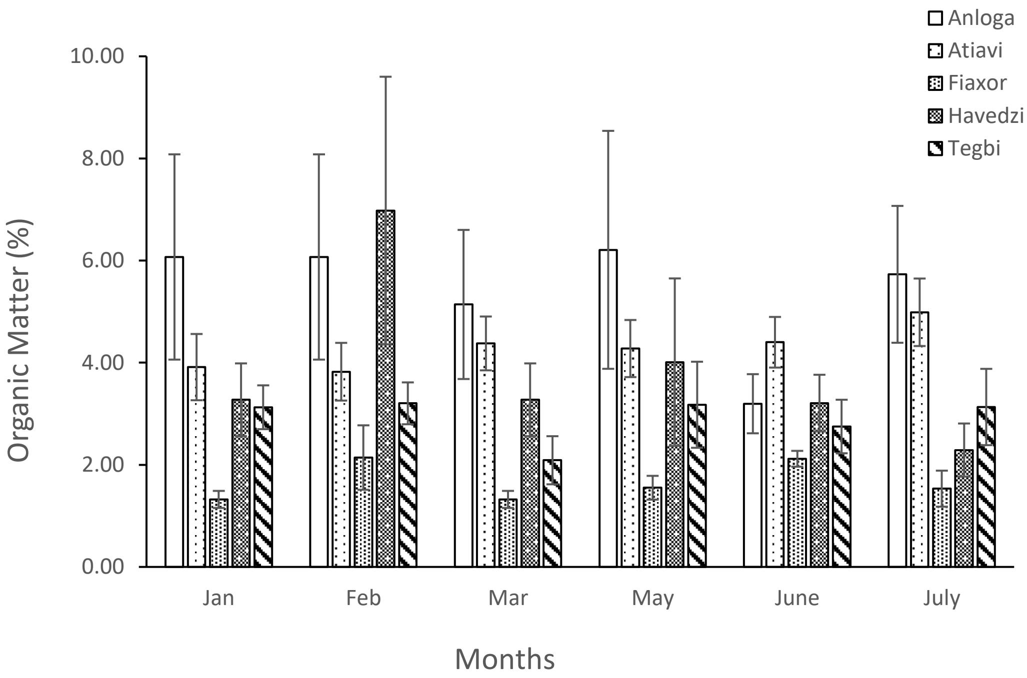

Figure 15: Monthly variations in organic matter content in sediment the five communities

4.4.2 Mean particle sizes (MPS)

All the sampling communities recorded coarse sand in January, February and March. For May, June, July, all the sampling communities except Fiaxor were dominated by very coarse sand. Fiaxor however, recorded coarse sand in those months (Table 3). There was statistical difference across the communities but no differences were recorded across the months.

Table 3: Monthly variations in MEAN PARTICLE SIZE in the five communities

Months	Anloga		Atiavi		Fiaxor		Havedzi		Tegbi	
	MPS (mm)	Grain type	MPS (mm)	Grain type	MPS (mm)	Grain Type	MPS (mm)	Grain type	MPS (mm)	Grain type
Jan	0.62	Coarse sand	0.96	Coarse sand	0.50	Coarse sand	0.76	Coarse sand	0.82	Coarse sand
Feb	0.62	Coarse sand	1.00	Coarse sand	0.61	Coarse sand	0.59	Coarse sand	0.73	Coarse sand
March	0.62	Coarse sand	0.92	Coarse sand	0.39	Medium Sand	0.93	Coarse sand	0.91	Coarse sand
May	1.23	Very coarse sand	1.18	Very coarse sand	0.46	Coarse sand	0.96	Coarse sand	0.87	Coarse sand
June	1.08	Very coarse sand	1.27	Very coarse sand	0.57	Coarse sand	1.01	Very coarse sand	0.86	Coarse sand
July	1.28	Very coarse sand	1.15	Very coarse sand	0.55	Coarse sand	1.09	Very coarse sand	1.17	Very coarse sand

4.5 Benthic Macroinvertebrate Taxonomic Groups.

The various macroinvertebrates identified in each community are covered in this section, together with their abundance, frequency of occurrence, and the percentage compositions of the most encountered species in each community, Shannon-Wiener indices, Pielou indices and Margalef indices. The term “species” is used in this section to refer to the different macroinvertebrate taxa encountered (Table 4), some of which were not identified beyond the phylum level. Taxonomic groups denoted (P), (M), (C) and (I) represents Polychaeta, Mollusca, Crustacea and Insecta, respectively.

Table 4: List of SPECIES identified in each community

Phylum/ Class	Family	Species list	Havedzi	Anloga	Tegbi	Fiaxor	Atiavi
Polychaeta	Capitellidae	*Notomastus latericeus*	+	+	+	+	+
Polychaeta	Capitellidae	*Capitella capitata*	+	+	+	+	+
Polychaeta	Capitellidae	*Heteromastus* sp.	+	+	+	+	+
Polychaeta	Nereididae	*Nereis* sp.	+	+	+	+	+
Polychaeta	Nereididae	*Neanthes alcheton*	+	-	+	-	+
Polychaeta	Eunicidae	*Eunice aphroditois*	+	+	+	+	+
Polychaeta	Eunicidae	*Eunice fasciata*	+	+	+	-	-
Polychaeta	Eunicidae	*Eunice* sp.	-	-	+	+	-
Polychaeta	Eunicidae	*Marphysa sanguinea*	+	+	+	-	-
Polychaeta	Phyllodocidae	*Eulalia viridis*	+	+	+	+	+
Polychaeta	Phyllodocidae	*Eulalia* sp.	+	-	-	+	-
Polychaeta	Nephtyidae	*Nephtys cirrosa*	-	+	+	+	+
Polychaeta	Orbiniidae	*Scoloplos* sp.	+	+	+	+	-
Polychaeta	Pilargidae	*Sigambra* sp.	-	+	-	+	+
Polychaeta	Polynoidae	*Lepidonotus oculatus*	-	+	+	+	-
Polychaeta	Cirratulidae	*Cirratulus* sp.	+	+	-	-	+
Crustacea	Gammaridae	*Gammarus* sp.	+	+	+	+	+
Crustacea	Mysidae	*Mysis* sp.	+	-	+	-	-
Mollusca	Thiaridae	*Melanoides tuberculate*	+	+	+	+	+
Mollusca	Hydrobiidae	*Hydrobia ulva*	+	+	+	-	+
Mollusca	Veneridae	*Tivela bicolor*	-	-	+	+	-
Mollusca	Veneridae	*Pitaria tumins*	-	-	-	-	-
Mollusca	Bithyniidae	*Bithynia funiculata*	+	-	+	+	+
Insecta	Chironomidae	*Chironomus* sp. (Larvae)	-	-	+	-	-

Note: + indicates the species were encountered in the communities and - indicates the species were not encountered the communities.

4.5.1 Richness and abundance

To compare species richness, the number of different species found in each community was collated. With a total of 13 different taxa, Atiavi had the least number of species at the end of the study period, followed by Anloga, Fiaxor, Havedzi and Tegbi with 15, 16, 17 and 19 taxa respectively (Table 5). Havedzi and Atiavi had the least number of species (4 species) in January and June respectively. Havedzi also had the highest number of species (11 species) in May. Most of the communities recorded their highest number of species in July. At the end of the 6 months study period, Anloga had the lowest number of organisms followed by Atiavi, Havedzi, Fiaxor and Tegbi in an increasing order ranging from 1213 to 3378. Havedzi and Anloga recorded their highest number of organisms in July. Tegbi and Fiaxor recorded their highest number in February and Atiavi also recoded its highest in January. Anloga and Havedzi recorded their lowest in January.

Table 5: Monthly BENTHIC MACROINVERTEBRATE ABUNDANCE in the communities

Months	Havedzi		Anloga		Tegbi		Fiaxor		Atiavi	
	Species	Individual organisms	Species	Individual organisms	Species	Individual organisms	Species	Individual organisms	Species	Individual organisms
January	4	114	5	98	6	332	8	356	7	448
February	6	116	6	128	6	710	9	574	8	249
March	8	357	9	225	9	498	7	419	8	277
May	11	490	6	245	6	714	7	369	8	331
June	7	374	7	182	6	527	6	285	4	289
July	9	596	9	381	9	673	9	537	5	370
All months	17	2047	15	1213	19	3378	16	2559	13	1992

*Values for all months represent the total number of species and individuals encountered for each community during 6 months sampling period

4.5.2 Species diversity

The species diversity in the various communities was compared using Shannon-Wiener diversity index. Table 6 shows the overall diversity indices for each of the five communities. Shanon-Wiener diversity indices were comparatively low in Tegbi (1.88). Fiaxor and Atiavi recorded the same diversity indices (1.95). Anloga and Havedzi followed suit with 2.15 and 2.16 respectively. Tegbi recorded the highest species richness (2.22) followed by Havedzi (2.10) > Anloga (1.97) > Fiaxor (1.91) > Atiavi (1.58). All the communities had their species evenly distributed since their evenness indices were above 0.5.

Table 6: Monthly ECOLOGICAL INDICES OF BENTHIC MACROINVERTEBRATES for the communities

Months	Havedzi			Anloga			Tegbi			Fiaxor			Atiavi		
	H’	**J’**	**D**	**H’**	**J’**	**D**	**H’**	**J’**	**D**	**H’**	**J’**	**D**	**H’**	**J’**	**D**
January	0.49	0.35	0.63	0.53	0.33	0.87	0.68	0.38	0.86	1.10	0.53	1.19	0.51	0.26	0.98
February	1.44	0.80	1.05	1.36	0.76	1.36	0.53	0.30	0.76	1.24	0.56	1.26	1.52	0.73	1.27
March	1.39	0.67	1.19	1.62	0.74	1.48	1.46	0.67	1.29	1.59	0.82	0.99	1.43	0.69	1.24
May	1.78	0.74	1.61	1.42	0.79	0.91	1.14	0.64	0.76	1.53	0.79	1.02	1.42	0.68	1.21
June	1.67	0.86	1.01	1.72	0.88	1.15	1.24	0.69	0.80	1.54	0.86	0.88	1.11	0.80	0.53
July	1.58	0.72	1.25	1.15	0.52	1.35	1.20	0.55	1.23	1.47	0.67	1.27	1.22	0.76	0.68
All months	2.16	0.76	2.10	2.15	0.80	1.97	1.88	0.64	2.22	1.95	0.70	1.91	1.95	0.76	1.58

4.5.3 Percentage compositions

Percentage composition of the most encountered species in the various communities was calculated and represented in Fig. 16. The highest species encountered in Tegbi was *Notomastus* sp., while *Capitella capitata* was the most encountered species in Havedzi. Anloga had *Eulalia* sp. as the most encountered species, while *Melanoides tuberculata* was the most encountered in Fiaxor, and *Heteromastus* sp. being the most encountered in Atiavi. Species labelled others were species that recorded less than 3% of the total percentage composition for all the community.

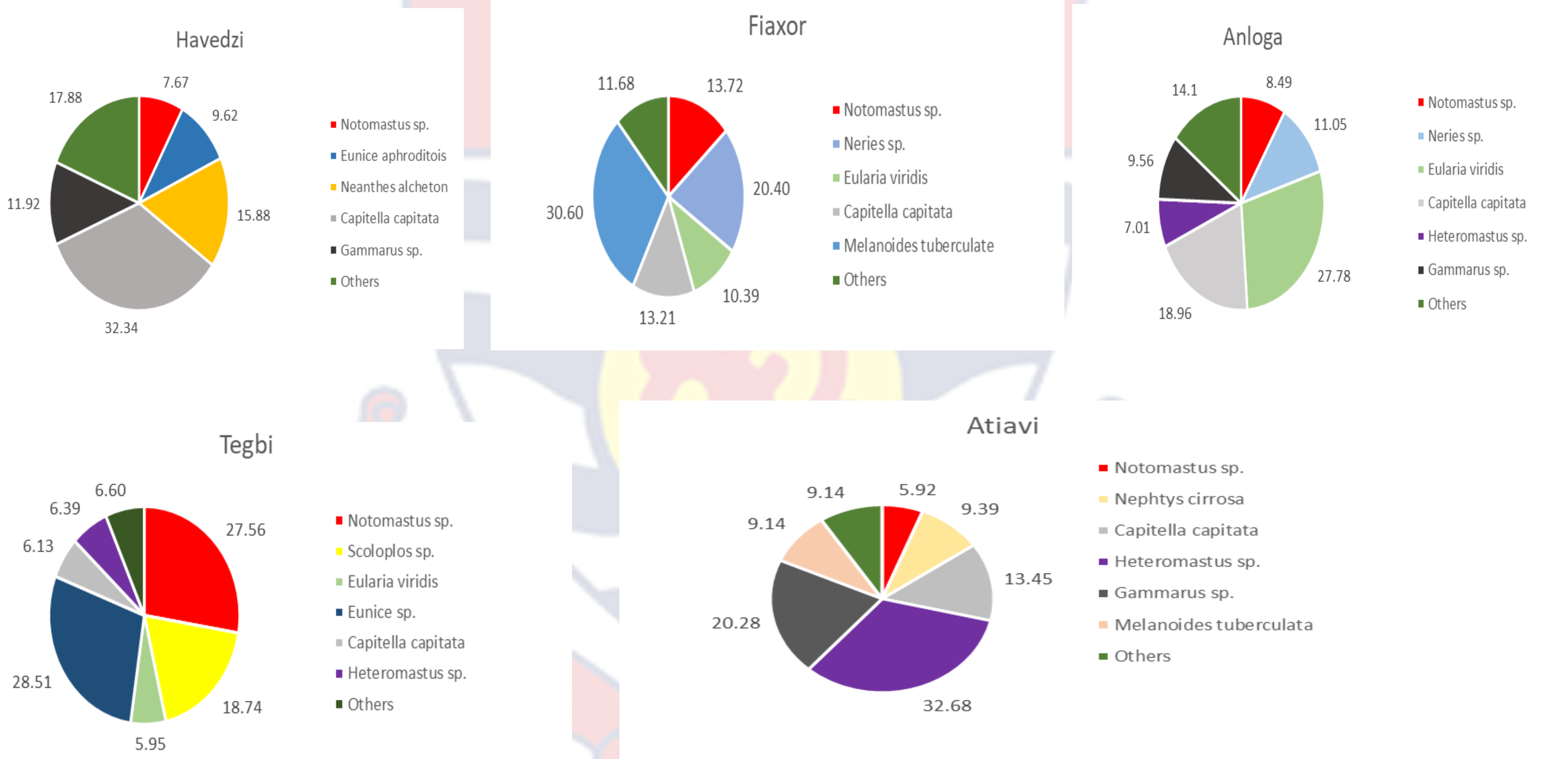

Figure 16: Percentage composition of numerical abundance of most encountered benthic macroinvertebrates in all communities

4.6 Environment-Benthic Macroinvertebrates Relationship

This section covers the findings on the effects of abiotic variables on the biodiversity of benthic macroinvertebrates. Canonical Correlation Analysis (CCA) was used determine the relationship between the abiotic variables and the benthic macroinvertebrates. From the analysis (Table 7), the physicochemical and sediment parameters had a significant effect on the number of individual organisms (p=0.049) but no significant difference on the species diversity, evenness and richness (Appendix F). It also showed that as pH, nitrate and organic matter decrease, benthic macroinvertebrates abundance increases. Benthic macroinvertebrates abundance increases as DO, conductivity, temperature, TDS, salinity, turbidity, phosphate and mean particle size increase.

Table 7: CANONICAL CORRELATION ANALYSIS showing the effects of abiotic parameters and the abundance of benthic macroinvertebrates

Variable	1	2
pH	-0.467	-0.226
DO	0.032	-0.161
Conductivity	0.157	-0.092
TDS	0.192	-0.099
Temperature	0.022	0.560
Salinity	0.118	-0.150
Turbidity	0.184	0.146
Nitrate- water	0.223	0.085
Phosphate- water	0.316	-0.105
Ch. *A*	0.005	0.321
Organic matter	-0.305	0.311
Nitrate- sediment	-0.315	0.014
Phosphate- sediment	0.134	0.115
MPS	0.164	0.096
Individuals	0.734	-0.530
Shanon-Wiener index	0.498	0.566
Pielou's index	0.373	0.861
Margalef's index	0.373	-0.140

CHAPTER FIVE

DISCUSSION

This chapter explains the observed trends in water quality parameters, sediment quality parameters, benthic macroinvertebrate taxonomic groups in the five communities studied. The findings have also been compared to similar works where necessary.

5.1 Water Quality Parameters

Water quality can be determined by the changes in physicochemical parameters such as temperature, nitrate and dissolved oxygen, among others, and their effects on aquatic organisms' biodiversity (Campanati et al., 2016; Mustapha, 2008). Key variables measured in this research were temperature, turbidity, conductivity, salinity, pH, DO, TDS, BOD, chlorophyll-*a*, pesticides, nitrate and phosphate. These parameters showed levels of monthly variations.

High dissolved oxygen in the communities in July may be as a result of strong winds which increased the aeration at that particular point of time. Again, high DO in some of the communities in January could be attributed to settling of sediment which increases light penetration and this enhances photosynthesis by phytoplankton. This was evident in the turbidity values which was low in January. Low DO concentrations in the communities in May could, however, be due to the rains. This possibly increased the turbidity of the water, which reduced light penetration to enhance photosynthesis. Also, rainfall runoffs may have introduced organic matter which used the DO to breakdown, thereby reducing the concentrations in the lagoon. This was evident in the BOD values which was high in those months. It may also be a result of aerobic activities such as respiration which use up oxygen in the water. Also, low DO concentrations recorded in March could be attributed to high temperatures observed at the time of sampling as increased temperature make oxygen molecules escape into the atmosphere. DO concentrations in the study range from 4.04 mg/L to 8.64 mg/L, and these values are within the ranges that are suitable (2.0 to 11.0 mg/L) for organisms in aquatic ecosystems (Behar, 1997). These values can also be compared to DO concentrations values reported by Lamptey and Armah (2008), Lamptey et al. (2013) and Avornyo (2017) in the Keta Lagoon. These studies reported DO values of 6.3 mg/L 6.1mg/L and 5.8 mg/L respectively.

Most aquatic organisms usually prefer a pH range of 6.5 to 9.0 (Fondriest Environmental Inc., 2013b). However, not all the communities studied had their pH values within this range. There was a decrease in pH values with the sampling months. High pH values were observed in the first 4 months of sampling and low values were recorded in the last 2 months of sampling. The high values may be due to the presence of planktonic algae that use up the carbon dioxide to photosynthesize and release oxygen into the water as this was evident in high chlorophyll-*a* values in March. Comparatively, Abowei (2010) reported high pH values in the Nkoro River of the Niger Delta during the dry season than in the wet season. Activities of living organisms and pollution from terrestrial environments can affect the pH of a water (Waller et al.,1996). High pH values may also be due to anthropogenic activities through the use of pesticides (through acid hydrolysis) and farming activities (transporting of excess fertilizers) around the lagoon.

Runoffs could introduce pesticides and fertilizers from the surrounding farmlands into the lagoons (Magna, Koranteng, Donkor & Gordon, 2022). Low values of pH could also be as a result of respiration and decomposition, which increase carbon dioxide levels (Fondriest Environmental Inc., 2013b). Studies by Lamptey and Armah (2008), Lamptey et al. (2013) and Avornyo (2017) in the Keta lagoon reported pH values of 7.7, 8.0 and 8.3, respectively. Comparing these three past studies to this current study show a trend of increasing alkalinity with time, since the values recorded in the first 4 months (8.2-10.37) were above these values. High pH values can however affect aquatic life in the lagoon (USEPA 2022). Also, low pH of water bodies can affect shell-forming organisms as this can dissolve their shells or prevent them from forming shells (Cooley & Doney, 2009).

Salinity of water is related to climatic conditions as it reduces due to dilution from rainfall or/and a freshwater source and increases due to evaporation (McLusky, 1989; Waller, Burchett & Dando, 1996). Low salinity in June and July could, therefore, was as a result of the rains, which diluted the water in the lagoon. High salinity in February and March could, however, be as a result of high temperatures that were recorded during that period, which resulted in evaporation. Conversely, the recorded high salinity levels could also be as a result of minimal rainfall during those months. Previous studies by Lamptey and Armah (2008) recorded mean salinity of 30.4 ppt and most of the values recoded in this study were below this value, which shows a decrease in salinity of the lagoon over time.

Fluctuations in temperature values may be due to varying weather conditions and mixing processes at the time. The recorded temperature values between 25 °C and 34 °C in the study may be as a result of the shallow nature of the lagoon (Dzakpasu & Yankson, 2015; Okyere, 2010). The low temperatures recorded in June and July and high temperatures in February, March and May could be due to climatic conditions in the southern part of Ghana, where temperature is mostly high in the dry season and cold in the wet season. Similar trends were observed in the Keta Lagoon by Avornyo (2017), Lamptey (2008) and Lamptey (2013), as well as in the Kakum and Nyan estuaries by Dzakpasu and Yankson (2015).

Conductivity values recorded in this study were stable, i.e., between 32 and 49 µS/cm. Months that recorded high conductivity values also recorded high salinity, and those that recorded low conductivity had low salinity. This is in line with what Poison (1982) and USEPA (2020) reported that conductivity can be related to salinity in a direct proportional manner. The observed conductivity values in this study could be attributed to agriculture runoffs, which could lead to an increase in nitrate, chloride, and phosphate ions in water (Fondriest Environmental Inc., 2014a).

Excessive TDS can reduce the clarity of water, which hinders photosynthesis and also lead to high temperatures in the water (USEPA, 1999). In this study, February, March and May in most of the communities recorded high TDS values, whereas June and July recorded low TDS values. This may be as a result of decaying organisms since it is one of the sources of dissolved solids in water (LEO Enviro Sci Inquiry, 2011). This was evident in the BOD values which were high in those months, as oxygen was used for decomposition which made the demand high.

Phytoplankton production, algal growth, re-suspension of bottom sediments, and runoff, among others, can influence the turbidity of water bodies (Kumar, Mishra, Equeenuddin, Cho & Rastogi, 2017). The high turbidity values recorded in March could be attributed to phytoplankton and algal growth since chlorophyll *a* was also high in that month. Also, high turbidity values recorded in Atiavi and Anloga could be a result of the shallow nature of the water, coupled with strong winds, which enable the mixing of the surface and bottom water. Turbidity values in all the communities did not reflect the rainfall pattern in the catchment area since turbidity in these communities fluctuated throughout the sampling months.

Phytoplankton and algae bloom in nutrient-rich conditions (Annick et al., 2016), which in turn, increases chlorophyll concentrations. High chlorophyll-*a* concentration implies that photosynthetic organisms have enough nutrients to bloom and photosynthesize. This was evident in the study whereby high chlorophyll-*a* concentration corresponded to high nitrate concentrations in March. Also, chlorophyll *a* concentration was mostly low in May, June and July. This may be as result of dilution of the water body by the rains and runoffs, thereby reducing the phytoplankton population and also washing surfaces containing algae.

Biological oxygen demand values were mostly high in May, June and July. This may be attributed to dead organisms and runoff of organic matter into the water body by the rains. These biotic remains use oxygen in the water for decomposition. Also, there was less phytoplankton for photosynthesis, which reflected in the chlorophyll-*a* result mostly around that time (2.26-3.79 µg/L). This made it possible for high demand of oxygen in the water body since more organisms used up less amount of dissolved oxygen.

5.2 Nutrients

Nitrates and phosphates, for example, are nutrients that naturally occur in small concentrations in aquatic habitats. However, eutrophication could occur if there is availability of excessive nutrients. (Nartey et al., 2012). They can also become excessive through anthropogenic activities.

Nitrate is carried into the water column when it binds with suspended sediments (Tang & Maggi, 2018). Inputs of nitrates in lagoons occur through runoff of chemical fertilizers or animal manure from farmlands and waste from sewage (Khan & Mohammad, 2014). In this study, nitrates values for both water and sediment were mostly higher in March, May, June and July. For water column, Atiavi and Anloga communities recorded high values throughout the study. This may be as a result of runoff carrying fertilizer and excreta from agricultural farms around the lagoon in these communities. The presence of bloom of weeds and the dark colour of the water in Anloga were clear indications of this. Water bodies in all the five communities studied had nitrate values above levels of 1.0 mg/L which are recommended in coastal waters (Behar, 1997; Nartey et al., 2012). Since the communities are close to the lagoon, the lagoon is therefore susceptible to receiving wastes that contain phosphates and nitrates. Previous studies in the Keta Lagoon by Avornyo (2017), Lamptey (2008) and Lamptey (2013) recorded nitrate levels between 1.00 mg/L and 1.20 mg/L respectively. Comparing the measured level nitrate from this study to these past studies shows the levels of nitrate in the lagoon is increasing with time.

Phosphate is the limiting factor in the growth of algae which is known to control primary productivity in coastal lagoons (Loureiro, Newton & Icely, 2005). High levels of phosphates concentrations in a lagoon may have resulted from anthropogenic activities. (Addo et al., 2014). Phosphate values in May, June and July were high in both the water column and sediment. This may be attributed to runoffs of nutrients and excreta from farmlands within the catchment. Phosphate values were above levels of 0.1 mg/L which are recommended for coastal waters (McCaffrey, 1997; Behar, 1997). Phosphate values recorded by Avornyo (2017), Lamptey (2008) and Lamptey (2013) were 0.2 mg/L, 0.27 mg/L and 0.28 respectively. Comparing these past studies to the current study show that the levels of phosphate in the lagoon is increasing with time.

5.3 Pesticides

Three types of pesticides residues were detected in the water medium of the lagoon. Chlorpyrifos was detected at Anloga and Fiaxor; Pirimiphos-methyl was detected at Havedzi; and Lambda-cyhalothrin was detected at Tegbi. Chlorpyrifos and Pirimiphos-methyl are organophosphates, whereas Lambda-cyhalothrin is a synthetic pyrethroid. These pesticides may have found their way into the lagoon through runoff from agricultural farms and/or through air pollution, which may have dissipated into the water body. They can be harmful to aquatic organisms as they can alter the biological processes such as reproduction of the organisms and can also bioaccumulate in the organisms since they hardly undergo degradation, and later biomagnify through the food web (True elements, 2020).

5.4 Sediment quality parameters

Benthic macroinvertebrate distribution is influenced by sediment particle size and organic matter content. (Allan, 1995; Ruellet & Dauvin, 2007). All the communities studied mostly recorded coarse sand in the first 3 sampling months (January, February, March) and very coarse sand in the last 3 sampling months (May, June, July). This may be the result of lager sized particles settling faster and more due to the speed at which the water is moving which makes smaller sized particles suspended in the water and makes it difficult to settle. The relatively low organic matter content reported at Fiaxor could also be as a result of the soil particle size (coarse sand) (Zink, Furtado, Casper & Schwark, 2004). Also, organic matter hardly increases in well-aerated soils of lagoons such as coarse sand and soil in warm climate because the added materials decompose rapidly (Bot & Benites, 2005). In this study, sites where high organic matter contents were recorded had less benthic macroinvertebrates.

5.5 Benthic macroinvertebrates

The distribution of benthic macroinvertebrate communities is influenced by environmental variables such as pH, temperature, dissolved oxygen, conductivity, organic matter content and sediment particle sizes (Allan, 1995). Therefore, any small changes in the environment reflects in the types and numbers of organisms living in the environment. The number of species of benthic macroinvertebrates in a water body can determine the quality of that water (Sallenave, 2015). This means that a polluted water body will have few species in it and the one with good quality will have greater number of species (Reizopoulou et al., 2014; Snelgrove, 1997).

In this study, Atiavi had the least number of species (13 species). This suggests that Atiavi had the poorest ecological health quality followed by Anloga (15 species), while Tegbi (19 species) had the best ecological health quality followed by Havedzi (17 species) and Fiaxor (16 species). The water bodies in the communities with less species also had high organic matter contents and the ones with higher number of species had low organic matter contents. Six (6) out of twenty-four (24) species encountered during the study were present in all the communities. These species are *Notomastus* sp., *Gammarus* sp. *Eunice* sp. *Eulalia viridis*, *Nereis* sp. and *Melanoides tuberculata*. Species composition and relative abundance of each species are also affected by changes in the environment (Olive & Dambach, 1973). *Capitella capitata* (polychaeta) dominated the Havedzi water body with 32.24 % followed by *Neanthes alchetron* 15.88 % (polychaeta) (Figure 4.15). These two species accounting for about 48.12 % of the total abundance at Havedzi raises concern. This is as a result of *Capitella capitata* being a pollution-tolerant species (Yankson & Kendall, 2001). Also, *Capitella capitata* is a good competitor for both food and space (Grizzle, 1984) which explains it dominating in the Havedzi water. *Heteromastus* and *Notomastus* spp. dominated the water body in Tegbi with a percentage of 28.51 % and 27.56 %, respectively and together made up 56.07 % of the total abundance of species encountered at Tegbi. At Atiavi, *Heteromastus* (polychaeta) and *Gammarus* (crustacea) spp. were the dominant species encountered with percentages of 32.68 % and 20.28 %, respectively, and constituted more than half (52.96 %) of the abundance of species present. *Eulalia viridis* and *Capitella capitata* (polychaeta) were the most encountered species in the water at Anloga with 27.78 % and 18.96% respectively. *Melanoides tuberculata* (Mollusca) and *Nereis* sp. were the dominant species encountered at Fiaxor with 30.60 % and 20.40 %, respectively, and together constituted over 50% of the total species present. *Melanoides tuberculata* has been described as an invasive species that disrupts aquatic environments due to a variety of characteristics, including its rapid dispersal rate (Vogler, Núñez, Gutiérrez Gregoric, Beltramino & Peso, 2013). *Nereis* sp. is euryhaline, therefore, its appearance and abundance in the lagoon can be explained, since the salinity level of the lagoon was high (21 to 32 ppt). Some of the polychaete species such as *Nereis* sp., *Capitella capitata Nephtys* and *Eulalia* spp. encountered in this study are pollution indicators. However, their presence in the lagoon could not be linked with pollution. This supports the idea of Olive and Dambach (1973) and Balogun et al. (2011) that, only a few pollution-tolerant species thrive in contaminated water basins when many pollution-sensitive species are removed and where there is little competition and abundant food supply. These organisms can survive in a wide range of environmental conditions however they have not been connected to the ecological health of water bodies (Olive & Dambach, 1973). Also, most of the physicochemical parameters of the lagoon which is used to determine the water quality fell within the acceptable range. The abundance of amphipod *Gammarus* sp. also suggest that there is little or no pollution in the lagoon (Ramachandra, Rishiram & Karthick, 2006).

A study by Lamptey and Armah (2008) reported that molluscs formed more than half of macroinvertebrates abundance in the Keta Lagoon. However, in this study, polychaetes dominated the lagoon. This shows a shift in the species composition in the lagoon. This observation may be as a result of sediment quality or food availability for these taxa (Nordhaus, Hadipudjana, Janssen & Pamungkas, 2009). The quality of the sediment or the availability of food might have changed which affects the molluscs but best suited polychaetes which might have caused a decline in molluscs and an increase in polychaetes.

Shannon-Wienner diversity index was comparatively lower in the Tegbi water (1.88) followed by Fiaxor and Atiavi (1.95 each). Havedzi however, was the most diverse community with a diversity index of 2.16. This could mean that most species taxa were encountered in the Havedzi water as compared to the others. Though Tegbi was the least diverse community, it happened to be the community that was most rich in individual species with a Margalef index of 2.22. Atiavi, on the other hand, was the least in species richness (1.58). This also means that the individual species encountered in Tegbi were more and that of Atiavi was the least compared to the other communities. Pielou's species evenness showed how the species in each community were distributed. The species in all the communities were evenly distributed since all had their indices above 0.50. However, Anloga (0.80) was most evenly distributed followed by Havedzi and Atiavi (0.76 each). Tegbi, on the other hand, was the least evenly distributed community. Therefore, it could be suggested that the biodiversity of benthic macroinvertebrates in the Havedzi water body was higher as compared to the other communities and the least was Tegbi. This could be that the water quality and sediment quality of those in Havedzi were suitable for the abundance of the benthic community as compared to the others. The diversity in this study was in the same range as the previous study by Lamptey and Armah (2008).

5.6 Environment-Benthic Macroinvertebrates Interactions

The last objective for this study was to determine the relationship between the water quality parameters, sediment quality parameters and the biodiversity of the benthic macroinvertebrates. The Canonical Correlation Analysis (CCA) was used to determine the relationship. The results of the CCA showed that benthic macroinvertebrates diversity was influenced by pH, nitrate and organic matter. Therefore, it is expected that, pH will decrease as nitrate decrease and so is organic matter. In all, these stated parameters have an effect on benthic macroinvertebrates abundance. This means that a decrease in these parameters caused an increase in benthic macroinvertebrates abundance. Organic matter has a significant effect on benthic macroinvertebrates abundance; high organic matter results in low number of organisms. This was evident in the current study, whereby the communities with low organic matter content recorded a high number of organisms. The analysis also showed that an increase in DO, conductivity, temperature, salinity, phosphates, chlorophyll *a* and mean particle size caused and increase in benthic macroinvertebrates abundance. The availability of nutrients increases the growth of phytoplankton and algae, which increases the chlorophyll-*a* concentration. High rate of photosynthesis also means that there is more production of DO favourable for an increase in benthic macroinvertebrates abundance in the lagoon. Increased salinity levels could also result in the abundance of euryhaline organisms such as *Nereis* sp. which are capable of living in high salinity environments. Increase in both salinity and temperature will also favour the survival, growth and reproduction of some organisms such as *Capitella capitata* that are able to survive under a wide variety of conditions (Olive & Dambach, 1973). In water bodies, the rate of primary productivity is increased when temperatures also increase (Lalli & Parsons, 1997). Therefore, increase in temperature will increase the rate of photosynthesis, increasing the DO levels, which will favour the growth and reproduction of some of the organisms. Sediment grain type also determines the number of organisms present in the sediment with high mean particle size means an increase in reproduction of organisms. It is generally known that there is a connection between faunal assemblages and sediment types (Jones, 1950). Medium grain size has a rich benthic fauna, whereas, the very fine sediment and the very coarse sediment have been observed to have poor benthic faunas (Harkantra, 1982). The sediment types recorded in the study were predominantly coarse sand, which encouraged moderate abundance of the organisms.

High concentrations of phosphate lead to the growth of algae and other aquatic plants which later decompose and use up oxygen release that might affect the survival, growth reproduction of aquatic macroinvertebrates (Kim et al., 2013). However, contrary to this, macroinvertebrates abundance increased with increasing phosphate concentrations. This could perhaps be because, the values were not that high to cause harm to the organisms. According to several research (Appiah, Etilé, Kouame & Koumelan, 2017; Horrigan, Choy, Marshall & Recknagel, 2005;

Shackleton, Holland, Stitz & McInerney, 2019), conductivity has an impact on benthic macroinvertebrates, with organisms decreasing as conductivity values increased. This was however, contrary to what was discovered in this study, where organism abundance increased as conductivity increased. This may perhaps, be that conductivity values were not that high to be detrimental to the organisms.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Biodiversity assessment in coastal lagoons has become a necessity since most of these ecosystems are being deteriorated by human activities, causing a decline in the organisms inhabiting these ecosystems. In view of this, this study aimed at assessing the biodiversity of benthic macroinvertebrates within the Keta Lagoon Complex Ramsar Site (KLCRS) since there is little information on these taxa in the wetland. Meanwhile, these organisms provide vital information on water quality and play important roles in the ecosystem, including serving as food for organisms higher in the trophic level. The study was done in five communities (sites) within the catchment area, namely Anloga, Havedzi, Tegbi, Atiavi and Fiaxor. These communities were selected to represent the human activities within the catchment area; fishing, salt mining, farming, cottage weaving and the reference site respectively. Sampling was done in January, February, March, May, June and July 2022, with the first three months representing dry season, and the last three representing wet season. Physicochemical parameters of water were measured *in situ* using appropriate meters in order to assess the water quality, while pesticides, nutrients, sediment particle sizes and organic matter determinations, as well as benthic macroinvertebrates identification measurements were done in the laboratory.

For the water quality analysis, temperature, salinity, conductivity, pH, DO, nitrates and chlorophyll-*a* concentration recorded high values in the first three months (January-March). Biological Oxygen Demand (BOD) and phosphate concentrations on the other hand, recorded high values in the last three months (May-July). Salinity, pH, conductivity, TDS, BOD and phosphate recorded no significant variations among communities (sites). For sediment quality parameters, phosphate concentrations were high in the last three months in most of the communities. Fiaxor recorded extremely high values in May and July, but recorded low organic matter content throughout the study period, whereas the other communities recorded high values. For mean particle size, coarse sand dominated the first three months, while very coarse sand dominated the last three months. Chlorpyrifos, lambda-cyhalothrin and pirimiphos-methyl were the pesticides detected in the lagoon.

Twenty-four (24) benthic macroinvertebrates species were encountered in the lagoon during the study. The highest number of species was recorded in Tegbi (19 species), followed by Havedzi (17 species), Fiaxor (16 species), Anloga (15 species) and Atiavi (13 species). Shannon-Wiener diversity index was lower in Tegbi, while Havedzi and Anloga had high diversity indices. The Canonical Correlation Analysis showed that, organic matter, chlorophyll-*a*, nitrate, salinity, temperature, and pH influenced species abundance.

6.2 Conclusions

The following conclusions are drawn based on the findings of the current investigation:

Physicochemical parameters such as DO, TDS and conductivity were within the acceptable limits, whereas nitrate, phosphate and pH were not within the acceptable limits for coastal waters. Also, comparing this study to previous studies in the Keta Lagoon, there is an increase with time in these parameters. Atiavi and Anloga were more turbid compared to the other communities. For pesticides, chlorpyrifos was detected in Fiaxor and Havedzi, pyrimiphos-methyl was detected in Havedzi and lambda-cyalothrin was also detected in Tegbi. The concentrations of the pesticides detected were in low concentrations compared to the permissible limits in water.

For sediment quality parameters, nitrate and phosphates concentrations were above the acceptable levels for coastal waters. No pesticides residue was detected in the sediment. This could be that most of the pesticides residue are soluble in water. Also, it may also be that the concentration in the sediment was small that they could not be detected in the samples. Fiaxor recorded the least organic matter content throughout the study sediment particle sizes was dominated by coarse and very coarse sand.

Atiavi had the least number of species. This suggests that Atiavi had the poorest ecological health quality followed by Anloga, while Tegbi had the best ecological health quality followed by Havedzi and Fiaxor. The biodiversity of benthic macroinvertebrates in the Havedzi water body was higher as compared to the other communities, and the least was Tegbi. Though Tegbi was the least diverse community, it was the highest in species richness and Atiavi was the least compared to the other communities. The species in all the communities were evenly distributed.

There was interaction between environmental parameters and abundance of benthic macroinvertebrates, whereby a decrease in nitrate and organic matter correlated positively to an increased abundance of the organisms and a decrease in pH correlated negatively to an increased abundance of the organisms. It can therefore be concluded that environmental parameters are key determinants of abundance of benthic macroinvertebrates in the KLCRS.

6.3 Recommendations

In the wake of decline in biodiversity in the KLCRS demonstrated in this study, studies on biodiversity and ecological health assessment are necessary to inform management policies. To further understand the dynamics that exist in the lagoon, longer-term investigations should be conducted in the future. Additionally, comparable research ought to be carried out in other lagoons in Ghana for a comprehensive approach to the sustainable management and conservation of benthic macroinvertebrates. In this study, parameters were assessed in water and sediment samples. Further studies on the effects of pollutants on benthic macroinvertebrates should be investigated to determine their susceptibility to anthropogenic stress. Again, numerical models should be employed to help understand the distribution patterns of nutrients and also to predict future nutrients concentration levels. There should also be strict regulations on agricultural activities that can minimize nutrients loading around the catchment areas of the lagoon.

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APPENDICES

Appendix A: ANOVA for Physicochemical Parameters

Appendix A1: Within communities (95 % confidence level)

	Df	Sum of squares	Mean square	F- value	P- value
Temperature	4	81.58	20.396	9.92	0.000
DO	4	21.55	5.3880	3.80	0.005
pH	4	2.11	0.526	0.54	0.704
Salinity	4	38.84	9.711	1.55	0.188
Turbidity	4	14917	3729.31	46.16	0.000
TDS	4	22.10	5.526	1.29	0.274
Conductivity	4	63.40	15.850	1.26	0.285
BOD	4	1.837	0.4592	1.16	0.331
Ch. *A*	4	228.3	57.074	23.65	0.000
Nitrate	4	680.3	170.06	8.80	0.000
Phosphate	4	37.16	9.291	2.17	0.072

Appendix A2: Within months (95 % confidence level)

	Df	Sum of squares	Mean square	F- value	P- value
Temperature	5	855.96	171.192	83.29	0.000
DO	5	101.36	20.2723	14.30	0.000
pH	5	1174.56	234.911	242.65	0.000
Salinity	5	2382.15	476.430	76.04	0.000
Turbidity	5	6977	1395.43	17.27	0.000
TDS	5	1821.23	364.245	85.14	0.000
Conductivity	5	4880.14	976.028	77.77	0.000
BOD	4	23.548	5.8869	14.82	0.000
Ch. *A*	5	409.6	81.921	33.95	0.000
Nitrate	5	3672.6	734.52	38.00	0.000
Phosphate	5	290.77	58.153	13.61	0.000

Appendix B: Tukey's Post Hoc Test for Physico-Chemical Parameters

Grouping Information Using the Tukey Method and 95% Confidence
Means that do not share a letter are significantly different.

Phosphate

Month	N	Mean	Grouping	
July	45	3.23067	A	
February	45	0.49733		B
March	45	0.46400		B
January	45	0.45289		B
June	45	0.42689		B
May	45	0.39578		B

Chlorophyll a

Site	N	Mean	Grouping			
Atiavi	54	5.67389	A			
Anloga	54	4.61796		B		
Tegbi	54	3.90852		B	C	
Fiaxor	54	3.47519			C	D
Havedzi	54	3.06704				D

Month	N	Mean	Grouping		
March	45	6.74578	A		
May	45	4.46000		B	
June	45	3.64889		B	C
July	45	3.49978			C
February	45	3.40911			C
January	45	3.12756			C

BOD

Month	N	Mean	Grouping	
July	45	2.32733	A	
May	45	2.28711	A	
June	45	2.26089	A	
February	45	1.78756		B
March	45	1.52311		B

Nitrate

Site	N	Mean	Grouping		
Atiavi	54	12.2398	A		
Anloga	54	9.8214		B	
Tegbi	54	8.9178		B	C
Fiaxor	54	8.8704		B	C
Havedzi	54	7.4357			C

Month	N	Mean	Grouping			
March	45	16.3701	A			
May	45	11.9529		B		
July	45	9.0114			C	
February	45	6.9848			C	D
June	45	6.5399			C	D
January	45	5.8830				D

Turbidity

Site	N	Mean	Grouping		
Atiavi	54	26.2219	A		
Anloga	54	21.5050	A	B	
Tegbi	54	17.7841		B	
Fiaxor	54	8.7104			C
Havedzi	54	6.7628			C

Month	N	Mean	Grouping		
March	45	24.4889	A		
May	45	19.4000	A	B	
July	45	18.2222		B	
February	45	14.3927		B	C
June	45	10.4667			C
January	45	10.2104			C

Salinity

Month	N	Mean	Grouping			
March	45	31.0331	A			
May	45	29.2029		B		
February	45	26.9964			C	
January	45	24.2702				D
June	45	23.9640				D
July	45	22.8236				D

Temperature

Site	N	Mean	Grouping	
Anloga	54	29.6952	A	
Atiavi	54	29.5613	A	
Havedzi	54	29.4769	A	
Fiaxor	54	29.3267	A	
Tegbi	54	28.1737		B

Month	N	Mean	Grouping				
March	45	32.0951	A				
February	45	30.0251		B			
May	45	29.9891		B			
June	45	29.0369			C		
January	45	27.8942				D	
July	45	26.4400					E

TDS

Month	N	Mean	Grouping			
March	45	29.0004	A			
May	45	27.5378		B		
February	45	25.6711			C	
June	45	23.0536				D
January	45	22.6918				D
July	45	22.0912				D

Conductivity

Month	N	Mean	Grouping			
March	45	47.6767	A			
May	45	45.1444		B		
February	45	41.6356			C	
June	45	37.7889				D
January	45	37.5089				D
July	45	36.1222				D

DO

Site	N	Mean	Grouping	
Tegbi	54	6.33741	A	
Havedzi	54	5.96333	A	B
Anloga	54	5.71648	A	B
Fiaxor	54	5.69630		B
Atiavi	45	5.48371		B

Month	N	Mean	Grouping		
July	45	6.77511	A		
January	36	6.21357	A	B	
June	45	6.16067	A	B	
March	45	5.58044		B	C
February	45	5.43556			C
May	45	4.87133			C

Hydrogen ion concentration (pH)

Month	N	Mean	Grouping			
January	45	9.59978	A			
March	45	8.87867		B		
February	45	8.52489		B		
May	45	8.41467		B		
June	45	5.23556			C	
July	45	3.92133				D

Appendix C: ANOVA of Sediment Parameters

Appendix C1: Within communities (95 % confidence level)

	Df	Sum of squares	Mean square	F- value	P- value
OM	4	432.52	108.129	10.90	0.000
MPS	4	9.307	2.3267	10.18	0.000
Nitrate	4	945.3	236.31	4.91	0.001
Phosphate	4	18.84	4.711	1.06	0.376

Appendix C2: Within months (95 % confidence level)

	Df	Sum of squares	Mean square	F- value	P- value
OM	5	50.58	10.116	1.02	0.406
MPS	5	4.637	0.9275	4.06	0.001
Nitrate	5	3367.0	673.41	14.00	0.000
Phosphate	5	39.42	7.884	1.78	0.118

Appendix D: Tukey's Post Hoc Test for sediment Parameters

Nitrate

Site	N	Mean	Grouping		
Fiaxor	54	15.9782	A		
Havedzi	54	15.1256	A	B	
Atiavi	54	14.3632	A	B	C
Tegbi	54	11.4856		B	C
Anloga	54	11.4774			C

Month	N	Mean	Grouping	
March	45	16.9997	A	
January	45	16.2618	A	
July	45	14.5697	A	
June	45	14.2648	A	
May	45	13.8221	A	
February	45	6.1978		B

Organic matter

Site	N	Mean	Grouping		
Anloga	54	5.40389	A		
Atiavi	54	4.29611	A	B	
Havedzi	54	3.83815	A	B	
Tegbi	54	2.91296		B	C
Fiaxor	54	1.66481			C

Appendix E: Pesticides residue analysed but not detected

TEST CODE	TEST CONDUCTED	UNIT
GHC	Lindane	ug/L
BHC	Beta-HCH	ug/L
DHC	Delta-HCH	ug/L
HEP	Heptachlor	ug/L
ALD	Aldrin	ug/L
GCH	Gamma-chlordane	ug/L
AEN	Alpha-Endosulfan	ug/L
BEN	Beta-Endosulfan	ug/L
DDE	p,p'-DDE	ug/L
END	Endrin	ug/L
DIE	Dieldrin	ug/L
DDD	p,p'-DDD	ug/L
DDT	p,p'-DDT	ug/L
ENS	Sulphate	ug/L
MET	Methoxychlor	ug/L
ETH	Ethoprophos	ug/L
DIA	Diazinon	ug/L
FEN	Fenitrothion	ug/L
MAL	Malathion	ug/L
CHF	Chlorfenvinphos	ug/L
ALL	Allethrin	ug/L
PRF	Profenofos	ug/L
PAE	Parathion-ethyl	ug/L
BIF	Bifenthrin	ug/L
FEP	Fenpropathrin	ug/L
PER	Permethrin	ug/L
CYF	Cyfluthrin	ug/L
CYP	Cypermethrin	ug/L
FEV	Fenvalerate	ug/L
DEL	Deltamethrin	ug/L

Appendix F: Significance value of canonical correlation analysis

	Correlation	Eigenvalue	Wilks statistic	F	Num DF	Denom D.F.	Significance
1	0.907	4.646	0.014	1.618	56.000	44.961	0.049
2	0.857	2.757	0.077	1.280	39.000	36.282	0.228
3	0.796	1.729	0.290	0.929	24.000	26.000	0.570
4	0.457	0.265	0.791	0.337	11.000	14.000	0.962